Enhancing cyanoacrylate with fingerprint powder instead of Basic Yellow 40

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Preface

The laboratory of the fingerprint specialists looks way different. […] The method they use most is the cyanoacrylate fume hood. A big fume hood in which some sort of glue is vaporized. The glue precipitates on the fingerprint, et voilà! It is visible and possible to photograph. […] If the fingerprint is not visible enough with cyano, which results in a white fingerprint, you can give it a color with Basic yellow 40. 'You'll get a 'Wie is de mol' logo.' The researchers show an example of a green yellow fingerprint.

I started my preface with a citation (translated from Dutch) from the book 'De wereld van de witte pakken – Mijn jaar bij de forensische recherche' – Tamara Seur, given to me by Jasper van der Duin (forensic investigator Dutch police force) (thanks for that). Tamara Seur is a reporter who joined the Dutch police force for a year. In this book, she tells about her experience at the Dutch police.

I used this citation for two reasons. The first reason is to show that cyanoacrylate is often used in (Dutch) forensic investigation. In addition, they also refer to Basic Yellow 40, which also shows that this is a dye (often) used. Therefore, this citation shows the importance of this research.

Secondly, I started my preface with this citation for a completely other reason. Namely, because this book also talked about other topics, both having and not having anything to do with dactyloscopy, which I've never heard of before. However, just before I read about these topics in the book, I learned about it at my internship. Because of that, I would like to thank Martin Eversdijk and René Gelderman for everything they taught me during my internship.

In addition, I would also like to thank Marije Wagenaar and Tristan Krap for the supervision from Hogeschool van Hall Larenstein, Lauren Harder for answering my questions regarding the current use of cyanoacrylate and BY40 at the Dutch police, my fellow intern Marlène Többen for the collaboration, and Daan Burger, Rianne van Dijk, Esra Hoogeveen, Romy Kuyvenhoven, Soeleka Mohamed, Johannes Oldersma, Jody Opgelder, Noah Teeling, and Marlène Többen for scoring the fingerprints.

Jacintha Knapen,

Nieuw-Vennep,

June 2020

Samenvatting

Vingerafdrukken kunnen worden gebruikt om mensen te identificeren. Een techniek om latente vingerafdrukken zichtbaar te maken is cyanoacrylaat (CA), welke de vingerafdruk wit kleurt. Dit kan gekleurd worden met verschillende kleurstoffen, zoals basic yellow 40 (BY40). BY40 heeft echter enkele nadelen; het is een toxische vloeistof die andere sporen weg kan wassen. Dit kan nadelig zijn wanneer een vingerafdruk deels latent en deels met bloed is geplaatst, waarbij het deel met bloed wordt weggewassen. Daarom is het doel van dit onderzoek om te onderzoeken of het kleuren van cyanoacrylaat met magnetisch poeder, fluorescent poeder, of poeder in suspensie mogelijk is plaats van BY40. In vergelijking tot BY40, hebben deze poeders minder tot geen nadelen.

Verschillende variabelen zijn onderzocht. Eerst werd onderzocht of CA beter direct na het opdampen gekleurd kan worden, of na een langere tijd (24 uur), in verband met het wegwassen. Daarnaast werd onderzocht of BY40 verdund (1:1, 1:8 en 1:18) gebruikt kan worden. Met de resultaten van deze twee deelonderzoeken is onderzocht of poeders net zo goed, beter of slechter werken dan BY40. Daarna werd onderzocht welke poeders het beste op verschillende ondergronden gebruikt kan worden, welke kleur poeder het beste werkt (aangezien BY40 geel is) en of bloedverbeteringstechnieken (aqua leuco crystal violet en Hongaars rood) na het kleuren van CA nog mogelijk is. Ook werd onderzocht of kleuren met poeders voordelen heeft ten opzichte van kleuren met BY40 op basis van kenmerken op het derde niveau en liften van de gekleurde vingerafdruk. De vingerafdrukken zijn gescoord door tien studenten (waarde 0-4). Op deze scores zijn Mann-Whitney U tests uitgevoerd om conclusies te kunnen trekken.

Uit het onderzoek bleek dat, in tegenstelling tot de huidige situatie, BY40 beter aangekleurd kan worden na 24 uur in plaats van gelijk na het opdampen (statistisch significant verschil). Dit was ook het geval voor fluorescent powder. Voor magnetisch poeder en poeder in suspensie was er geen statistisch significant verschil. Het onderzoek naar de verschillende concentraties van BY40 toonde aan dat er geen statistisch significant verschil was tussen de verschillende concentraties. Echter, in echte zaken zou een lagere concentratie een beter resultaat kunnen geven aangezien daarbij de ondergronden niet van tevoren schoongemaakt zijn met ethanol, waardoor achtergrondkleuring de vingerafdruk kan verstoren. Ook bleek dat er geen statistisch significant verschil is tussen BY40 en de drie verschillende poeders; ze werken allen even goed. Het onderzoek toonde echter ook aan dat het gebruikt van derde niveau kenmerken bij alle methodes niet mogelijk is. Dit ligt niet aan het kleuren van de CA, maar aan de CA zelf, welke te dicht is om van derde niveau kenmerken gebruik te maken. Hierom wordt het aangeraden om dit deel van het onderzoek te herhalen met vacuüm CA. Uit het deelonderzoek van het liften van BY40 kwam dat dit het beste plaats kan vinden met een zwarte gelatin lifter, welke voor minimaal vijftien minuten op de vingerafdruk geplaatst wordt. In tegenstelling de verwachtingen, werkte fluorescent poeder op plastic beter dan poeder in suspensie. Er werd verwacht dat fluorescent poeder slechter zou werken vanwege de statische lading die het aanbrengen zou veroorzaken. Voor glas was er geen statistisch significant verschil tussen de poeders. Voor aluminium werkt poeder in suspensie beter dan fluorescent poeder, voor geverfd hout werkt magnetisch poeder beter dan poeder in suspensie en voor niet geverfd hout werken zowel magnetisch poeder als fluorescent poeder beter dan poeder in suspensie. Verder waren er geen statistisch significante verschillen. Uit het onderzoek bleek ook dat het roze poeder een slechter resultaat gaf dan de andere kleuren. Dit komt waarschijnlijk doordat het roze poeder van een ander merk afkomstig is. Als laatste, toonde het onderzoek aan dat bloedverbeteringstechnieken niet mogelijk zijn na het kleuren van CA. Uit verder onderzoek bleek dat dit zeer waarschijnlijk niet aan de kleuringsmethoden ligt, maar aan de CA zelf.

Samenvattend kan geconcludeerd worden dat het kleuren van CA met poeders voordelen heeft ten opzichte van het kleuren met BY40 en het wordt daarom aanbevolen om verder te onderzoeken en te valideren.

Summary

Fingerprints can be used to identify people. A technique to make latent fingerprints visible is cyanoacrylate (CA), which colors fingerprints white. This can be enhanced with different dyes, like basic yellow 40 (BY40). However, BY40 has several drawbacks; it is a toxic liquid, which might cause other traces to be washed away. This can be disadvantageous if a fingerprint is partly latent and partly placed with blood; the part placed with blood can be washed away. Therefore, the aim of this study is to investigate whether enhancement of CA is possible with magnetic powder, fluorescent powder, or powder in suspension instead of BY40. In comparison to BY40, the powders have less to no drawbacks.

Different variables are investigated. First, it was investigated whether it is better to enhance CA right after CA fuming or after a longer period of time (24 hours), due to the possibility of CA being washed away. In addition, it was investigated whether BY40 could be used diluted (1:1, 1:8, and 1:18). With the results of these two studies, it is investigated whether powders work as good, better or worse than BY40. In addition, it was tested which powder works best on different surfaces, which powder color works best (since BY40 is yellow), and whether blood enhancement techniques (aqua leuco crystal violet and Hungarian red) are possible after enhancement of CA. During this research, it was also studied whether enhancement with powders is beneficial regarding third level features and lifting of the enhanced fingerprint. All fingerprints are scored by ten students (score 0-4). With these scores, Mann-Whitney U tests are carried out to be able to draw conclusions.

The research showed that, in contrast to current use, it is better to enhance CA with BY40 after 24 hours instead of right after CA fuming (statistically significant difference). This was also the case for fluorescent powder. For magnetic powder and powder in suspension, there was no statistically significant difference. The research into the different concentrations BY40 showed that there are no statistically significant differences between the different concentrations. However, in real cases, a lower concentration could give a better result since the surfaces are not cleaned with ethanol beforehand, which might cause disturbance of the fingerprint due to the enhancement of the surface. There is no statistically significant difference between BY40 and the three different powders; they all work as good. However, the research also showed that the use of third level features is not possible. This is not due to the enhancement of CA, but because of the CA itself, which is too dense to use third level features. Because of this, it is recommended the repeat this part of the research with vacuum CA. The part of the research regarding the lifting of BY40 showed that this works best with a black gelatin lifter, which is placed on the fingerprint for at least fifteen minutes. In contrast to the expectations, fluorescent powder worked better on plastic than powder in suspension. The expectations were that fluorescent powder would not work well due to the electrostatic charge caused by applying the powder. For glass, there was no statistically significant difference between the powders. For aluminum, powder in suspension works better than fluorescent powder, for painted wood, magnetic powder works better than powder in suspension, and for not painted wood, both magnetic powder and fluorescent powder work better than powder in suspension. Furthermore, there were no statistically significant differences. The research showed that the pink powder gave worse results than the other powders. This is most likely because the pink powder is from a different brand. Finally, this research showed that blood enhancement techniques are not possible after the enhancement of CA. Further research showed that this most likely is not caused by the enhancement techniques, but the CA itself causes the problem.

Summarizing, it can be concluded that the enhancement of cyanoacrylate with powders shows benefits regarding enhancement with BY40 and it is therefore recommended to put more research into it and to validate it.

Contents

1. Introduction

A terrorist attack took place in a tram. Several people got killed and the perpetrator escaped. According to several eyewitnesses, the perpetrator held on to several objects (poles and chairs) in the tram trying not to fall while moving forwards. The crime scene investigators decided to use a cyano-shot to make fingerprints visible in the tram. However, some of the fingerprints were placed on white surfaces and therefore lack contrast.

The (fictional) case above, describes an example in which cyanoacrylate is used to make fingerprints visible on the crime scene. In forensic investigation, fingerprints can be used to identify people, since they are sufficiently unique to distinguish people from one another since everybody has different fingerprints (Chen et al., 2009; Han et al., 2005). Identification takes place with the help of dactyloscopic points (see *1.1.1 Identification with the help of fingerprints*). The problem with this case, however, is that some of the fingerprints are deposited on white surfaces. Since cyanoacrylate is also white (see *Cyanoacrylate fuming*), it should be enhanced to make it visible. Currently, this is done with dyes. The dye most often used by the Dutch police and the Netherlands Forensic Institute (NFI) is Basic Yellow 40 (BY40) (Netherlands Forensic Institute, 2018). However, dyes have several drawbacks:

- Not durable and damaging to the user.
- Liquid and might therefore wash away other traces.
- Flammable.
- Expensive compared to other methods.
- Only available in yellow.
- BY40 cannot be used on the crime scene since it contains ethanol.
- DNA-investigation cannot take place after enhancement with BY40. The NFI itself states that after the treatment of BY40, sampling for DNA is not promising, since the DNA will be washed away due to the process of applying the dye and the washing step (Netherlands Forensic Institute, 2018). In addition, the DNA will also be damaged by the ethanol in BY40.

Because of the multiple drawbacks of BY40 written above, there is a demand for a new method to enhance cyanoacrylate, with less to no drawbacks. Therefore, it will be tested whether enhancement with powders is possible. Enhancement of cyanoacrylate with powders is already described in some books and articles, but no research into the use of it, for example how good it works compared to other enhancement techniques, is carried out yet (Menzel et al., 1983; Sampson, 1992). Therefore, the usability, and the advantages and disadvantages of both BY40 and enhancement with three different fingerprint powders are tested during this research. The fingerprint powders used are magnetic powder, fluorescent powder, and powder in suspension. These three powders were chosen since they cover a wide range of powders; they are all applied different and attach to the fingerprint different (see also *Physical methods*). Some powders show similarities to BY40 (for example suspension is also liquid). However, the other drawbacks of BY40 (flammable, contains ethanol, etc.) do not apply for those powders.

The variables/parameters chosen and the reason for that, are described below. After that, the theoretical information to understand the methods used, is described in *1.1 Theoretical framework*, followed by the research questions which arise from the different variables/parameters that will be tested.

Optimal time between cyanoacrylate fuming and enhancement. Currently, BY40 is applied right after cyanoacrylate fuming, or after some time, depending on the investigator (see *Appendix VIII – Interview Lauren Harder*). The BVDA states that it is better to apply BY40 after the cyanoacrylate is hardened

(see *Basic yellow 40 (BY40)*), but no other researches are found concerning this subject. Therefore, this will first be investigated to be able to confirm the statement of the BVDA. After the optimal time between cyanoacrylate fuming and enhancement with BY40 is found, this also must be found for the three powders to be able to make a fair comparison between the best results regarding time-interval.

Optimal concentration BY40. Currently, BY40 is used as delivered by the BVDA (so not diluted, see *Appendix VIII – Interview Lauren Harder*). However, there are several benefits of diluting BY40: it is cheaper since BY40 is more expensive than ethanol (solvent), and less contamination of the surface will take place. However, till now, no research has been put into this.

BY40 and Lumicyano™ vs powdering. If the first part of the research shows that enhancement of cyanoacrylate with powders is possible, it also must be compared to BY40. This, to investigate whether it shows better, similar or worse results than BY40. In addition, it is also compared to Lumicyano™. The reason for this is that Lumicyano™ is researched quit a lot, but it shows quit differing results (see *Luminescent cyanoacrylate*). Therefore, it has to be made sure that it is worth it putting more effort into investigating enhancement with powders if it turns out to be successful, and that it will not be useless since Lumicyano™ turns out to be better than powdering and will be applied to the forensic field quit soon, making enhancement techniques unnecessary.

Third level features. Investigation into third level features is taken into account since this might be used in cases where identification with the help of the twelve dactyloscopic points (see *1.1.1 Identification with the help of fingerprints*) is not possible. If the results show that enhancement with one technique makes using third level features possible but the others do not, the choice can be made for fingerprints of which it is already expected that twelve points will not be found, to use the technique with which third level features are possible to use, instead of a technique at which this is not possible.

Lifting (BY40 and powders). Lifting of fingerprints can be useful if these are deposited on a curved surface. Lifting offers a flat fingerprint, which is easier to identify. Therefore, it will be tested whether lifting works better with fingerprints enhanced with BY40 or with fingerprints enhanced with one of the three powders. Currently, no research is carried out regarding lifting of BY40. The only information found is from the BVDA (see *Discussion and recommendations*). The BVDA states that a fingerprint stained with a staining solution after cyanoacrylate can be lifted with a black gelatin lifter. However, the time the lift should be applied to the fingerprint is not mentioned. Therefore, this will be investigated first, and after that, the optimal settings will be used and compared to the lifts of the cyanoacrylate enhanced with powders.

Surface materials. Certain powders can be used better on certain surface materials than other powders. For example, the brush of the fluorescent powder will cause electrostatic electricity, causing the fingerprint to be dense which makes it impossible to distinguish the ridges from one another. So, there is already information available regarding which powders can be used best on what surface materials, but the effect of cyanoacrylate is not known. To be able to get the best result on each surface material, this must be investigated.

Colors. One of the drawbacks of BY40 is that it is only available in yellow. This might have drawbacks if the surface also fluoresces at the same wavelength at which BY40 is excited. If a powder color can be chosen that will be excited at a different wavelength, the background noise due to the fluorescence of the surface can be reduced. Therefore, it must be tested whether there are differences regarding how well the different colors are seen by the different raters, and whether there are differences between the powders.

Blood enhancement techniques. When a fingerprint is placed partly latent and partly with blood, the use of BY40 might not be beneficial to the part placed with blood, since it might wash away that part and it contains ethanol which damages the DNA present in the blood. Therefore, a technique is desired that will not cause any damage to the part placed with blood. However, it must be tested whether blood enhancement techniques are still possible to use after enhancement with powders, and whether this indeed works better than if the cyanoacrylate is enhanced with BY40.

1.1 Theoretical framework

1.1.1 Identification with the help of fingerprints

Different studies have been carried out on the distinctive value of fingerprints. The first classification system was published in 1900 and officially introduced in 1901 (Kuhne, 1916). The Galton-Henry classification, developed by Henry in 1900, carries the base for the identification of fingerprints nowadays (S. H. James et al., 2014). The method describes six main shapes for fingermarks; arch, tented arch, left loop, right loop, plain whorl, and twin loop. In addition, deltas and cores were also used for the identification (Mirzaei et al., 2013).

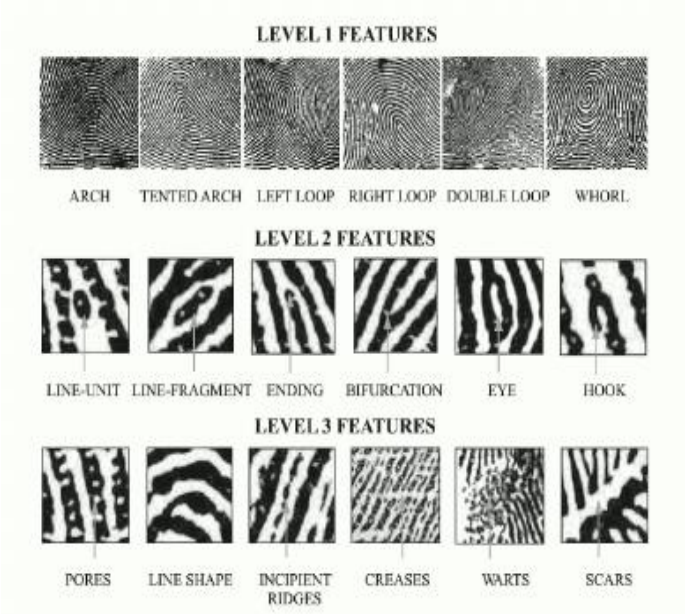

Figure 1; identification with the help of three levels of features in fingerprints (Mieloch et al., 2008). Identification with the help of fingerprints is done in three different levels of features. The first level features include the macro details of the fingerprint; the overall pattern. The second level features include the minutiae. These level two features have the discriminating power to individualize persons. The third level features include the attributes of a ridge. Examples of this are pores, scares, and warts.

The features of fingerprints can be divided into three levels (Jain et al., 2007) (see Figure 1). The first level features include macro details such as the overall shape of the fingerprint. Nowadays, those level 1 features are extended to ten different shapes (Delcom, n.d.). The second level features include the minutiae, for example ending or bifurcation. The third level features include attributes of a ridge (Mieloch et al., 2008), for example pores, warts or scars. Currently, in the Netherlands, the first and second level features are mainly used to match two fingerprints (Riemen & Voorhoeve, 2015). If the first level features of the two fingerprints is the same, and twelve corresponding level two features are found, there is a match. In addition, no difference can be visible (Broeders & Muller, 2008).

1.1.2 Making fingerprints visible

Fingers (and feet) contain pores through which sweat can leave the fingers. Sweat contains amongst others amino acids, fatty acids, triglyceride acids, and wax esters. Most methods for the development of latent fingerprints are based on detecting or visualizing those compounds (S. H. James & Nordby, 2009). After touching a substrate with the finger, sweat with these compounds will be left behind creating a fingerprint on the substrate. Fingerprints can be latent, plastic or visible (Langford et al., 2005). A fingerprint is called visible if there is enough contrast to distinguish between the fingerprint and the surface, by human eye (Broeders & Muller, 2008). A fingerprint is called plastic if it has been impressed in a soft, malleable surface (Sari et al., 2018). A latent fingerprint, which is not visible with

the naked eye, can be made visible with the help of chemical, physical and optical techniques (Croxton et al., 2010).

1.1.2.1. Physical methods

A commonly used method for making latent fingerprints visible physically, is powdering. Powdering relies on the mechanical adherence of fingerprint powder to the moisture and oily components of the fingerprint (Ramotowski, 2012). Different factors that affect the binding of powder to fingerprints are (Ramotowski, 2012):

1. **Particle shape**; the more surface area, the better contact with the fingerprint deposits.
2. **Surface chemistry of the powder particle**; coatings or molecules on the surface of the powder particle affect the interaction between the particle and the medium (fingerprint or surface).
3. **Electrostatic charge on the particle**; if particles are charged, the value of attractive Coulomb forces (forces between two stationary, electrically charged particles) exceeds that of other contributions to adhesion (Zimon, 1969).
4. **Adhesion to grease or liquid**; the more liquid and grease in a fingerprint deposit, the better the adhesion of the particle.
5. **Low adhesion to surface**; the powder must adhere better to the fingerprint deposit than to the surface. In addition, auto adhesion (the interaction between individual powder particles) can fill up the surface.

There are a lot of different powders that can be used; which one will be used depends mostly on the surface the fingerprint is deposited on (Lee & Gaensslen, 2001). Powders that will be used during this research are magnetic powder, powder in suspension, and fluorescent powder.

The fingerprint powder in magnetic powder itself is not magnetic; the colored particles are wrapped around magnetic filings. Those filings are attracted by a magnet and carried as whiskers by a magnetic wand. Because of this, only the powder touches the trace and not the wand. This decreases the chance of damaging the trace (Wertheim, 2013). By doing this, the colored particles will attach to the fingerprint residue and the magnetic filings stay at the wand.

Powder suspensions are a mixture of insolvable powder particles in a solution. The suspension is applied as a spray, painted, or dipped and rinsed with water. Since the powder particles in the solution do not dissolve in water, the particles can selectively adhere to the fingerprint residue, since the water soluble components will be washed away (Daluz, 2018).

Besides the traditional fingerprint powders, there are also luminescent fingerprint powders (Lee & Gaensslen, 2001). Luminescence can be divided into fluorescent and phosphorescent powders. These powders luminesce upon exposure to light (Dalrymple et al., 1977). These powders are mostly used on multicolored surfaces (Lee & Gaensslen, 2001).

1.1.2.1. Optical methods

Different optical methods have been researched over the years. Optical methods are non-invasive and therefore recommended to carry out before any chemical treatment. Examples of these optical methods include polarization and specular reflection, near infra-red, and coherence tomography (Chang et al., 2011; Lin et al., 2005; Zhang et al., 2019).

1.1.2.2. Chemical methods

A commonly used chemical method to visualize fingerprints is chemical fuming. An example for this is iodine fuming. With this, an interaction takes place involving physical absorption. If the iodine crystals are warmed, they produce a violet vapor (Lee & Gaensslen, 2001).

Besides iodine fuming, there are other methods. One example of this is ninhydrin. Ninhydrin can be used on porous substrates (Lennard, 2019). Ninhydrin reacts with the amino acids of the fingerprint and forms an adduct called Ruhemann's Purple (S. H. James & Nordby, 2009).

Another chemical method for making latent fingerprints visible, is cyanoacrylate fuming. This method will also be used during this research and therefore further explained in the chapters below.

1.1.2.2.1. Cyanoacrylate fuming

Cyanoacrylate is a super glue and was first used in 1982 (Ramotowski, 2012). Since then, several studies have been conducted regarding the understanding and developing of the method (Czekanski et al., 2006; Lewis et al., 2001; Wargacki et al., 2007). In addition, the method is accelerated using heat and water vapor (Olenik, 1984).

Cyanoacrylate is placed high in the sequence of methods which are used on nonporous surfaces; at the third place, right after visual, and inherent fluorescence by laser or alternate light source (Ramotowski, 2012; Trozzi et al., 2000) In the Netherlands, it is used on almost all non-porous surfaces (see *Appendix VIII – Interview Lauren Harder*).

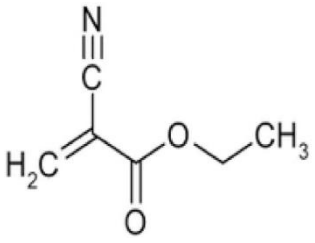

Figure 2; Chemical structure of Ethyl Cyanoacrylate (Bumbrah, 2017). This image shows the structure of ethyl cyanoacrylate which is in this form before polymerizing.

The mechanism of cyanoacrylate fuming can be divided into three main steps: (1) initiation, (2) propagation, and (3) termination (Ramotowski, 2012). Cyanoacrylate is an electrophile due to the carbon double bond (shown in Figure 2), meaning it accepts electrons (Ashenhurst, 2012). The polymerization is initiated by the nucleophile (donates electrons). This nucleophile attacks the carbon containing the double bond, with an electron transferring to the double bonded-oxygen (see Figure 3). Therefore, the negative charge is held at the second carbon. Because of that, a second molecule of ethyl cyanoacrylate can bind to the first molecule. The growing polymer serves as a nucleophile and continues to propagate the polymerization until the reaction is terminated when the monomer supply is exhausted or the propagating anion collides with a terminating agent (see Figure 3) (Ramotowski, 2012).

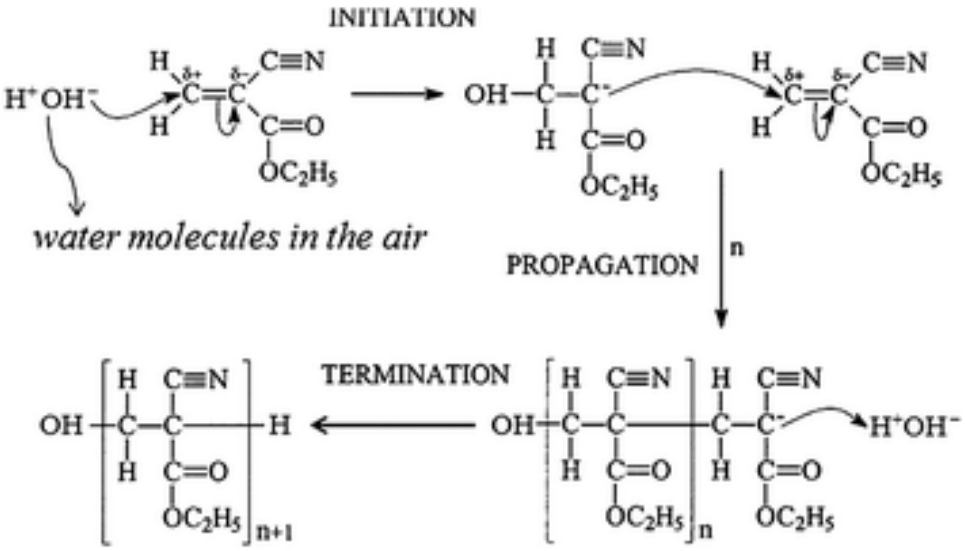

Figure 3; formation of polymerized ethyl cyanoacrylate (Liu et al., 2013). Polymerized ethyl cyanoacrylate will be formed out of ethyl cyanoacrylate in three steps: initiation, propagation, and termination.

Since the cyanoacrylate deposits as a white color, it often lacks contrast. Methods to enhance the visibility of the cyanoacrylate can be used. Some examples to enhance the cyanoacrylate include

staining with different dyes, or in some cases powdering (Ramotowski, 2012). An example of these dyes is BY40. Powdering after cyanoacrylate fuming is currently not used in the Netherlands.

1.1.2.2.1.1. Basic yellow 40 (BY40)

BY40 is a dye used to enhance cyanoacrylate and is mostly used on white or multicolored surfaces since cyanoacrylate is white. About five percent of the traces enhanced with cyanoacrylate will be enhanced with BY40 (see *Appendix VIII – Interview Lauren Harder*). BY40 fluoresces under blue/purple light. BY40 can be ethanol-based, methanol-based or water-based. According to the Home Office Police Scientific Development Branched the aqueous BY40 has health and safety advantages, but does not work as well as the ethanol-based BY40 on some surfaces (Ramotowski, 2012). The methanol-based one causes too much damage to the traces and surface and has even more health and safety-issues than the ethanol-based one and will therefore not be used during this research. BY40 can destroy certain surfaces due to the presence of ethanol. BY40 can also be used as a dilution, depending on the background noise. The MSDS of methanol-based and ethanol-based BY40 is presented in *Appendix VII – MSDS BY40*.

BY40 can be applied in various ways; spray, pouring, brush, or dabbing. After ten to sixty seconds, the remainder must be removed by rinsing it with water.

Till now, no studies were found regarding the time between cyanoacrylate fuming and BY40. The only source found is from the BVDA, which states (translated from Dutch):

> *Before the dye is applied, it is important that the cyanoacrylate on the fumed object got time to harden. Otherwise, the fresh cyanoacrylate traces will be washed away, or partially washed away by the dye. So, wait before applying the dye, enhance the objects for example the next day.*

However, sometimes, BY40 is still applied right after cyanoacrylate fuming (see *Appendix VIII – Interview Lauren Harder*).

1.1.2.2.2. Luminescent cyanoacrylate

Luminescent cyanoacrylate (Lumicyano™) is developed to carry out cyanoacrylate fuming and enhancement in one step since it already contains dyes. Therefore, being less time-consuming and less damaging to the user (Prete et al., 2013). A dye copolymerizes with the cyanoacrylate fumes (Ramotowski, 2012).

The study by Prete, et al. (2013) showed that Lumicyano™ had equal or better sensitivity and ridge details than currently used cyanoacrylate (Prete et al., 2013). On the contrary, the research of Chadwick, et al. (2014) shows that the luminescence of the Lumicyano™ was weaker than conventional cyanoacrylate-developed fingermarks stained with rhodamine 6G (Chadwick et al., 2014). In addition, the research of Farrugia, et al. (2015) also compared cyanoacrylate enhanced with BY40, with Lumicyano™. This research showed that the enhancement with BY40 shows fingerprints with a higher quality than the Lumicyano™ (K. Farrugia et al., 2014). Concluding, the results of Lumicyano™ are varying.

1.1.3. Lifting fingerprints

Lifting of fingerprints makes it possible to collect fingerprints from a crime scene and take it to the laboratory. Lifting is also useful if, for example, cyanoacrylate is enhanced with a fluorescent dye/powder, but the surface itself also fluoresces. By lifting the dye/powder with a non-fluorescent lifter, the fingerprint gets visible better. Lifting is also used to increase the contrast; a bright powder (e.g. yellow) can be lifted best with a black lifter and a dark powder (e.g. black) can be lifted best with a white lifter. Lifting is most compatible with flake powders but less appropriate for granular and

magnetic powders. There are different types of fingerprint lifters: adhesive tapes and sheets, gelatin lifters, and casting compounds. Adhesive tapes and sheets are mostly used on flat surfaces and casting compounds mostly on highly textured surfaces (Ramotowski, 2012).

During this research, gelatin lifts will be used since these are mostly used by the Dutch police. These are available in different colors which makes it possible to enhance the contrast between the powder and the lifter, and they are flexible. These lifts are better suited for lifting of marks powdered with granular and magnetic powders (BVDA International, 2008). There is also a difference between the white and black gelatin lifters; one can lift certain things better than the other, and the other way around.

1.1.4. Fingerprints in blood

On crime scenes or objects, fingerprints can be found that are partly placed with blood and partly latent. With fingerprints like this, it is important to make the latent part of the fingerprint visible, but blood enhancement techniques regarding the part of the fingerprint placed with blood also still must be possible. In this research, two different techniques for the enhancement of blood are used: aqua leuco crystal violet (ALCV) and Hungarian Red.

1.1.4.1. Aqua Leuco Crystal Violet (ALCV)

Aqua leuco crystal violet (ALCV/LCV) turns purple when it comes into contact with hemoglobin (Bodziak, 2000). The reaction that occurs at that moment is shown in Figure 5. This figure shows ALCV being colorless, but after an oxidation reaction with hemoglobin and hydrogen peroxide, which is added to the ALCV before use, one double bond of the benzene-group shifts to a single bond at the center of the molecule, and a double bond appears at the nitrogen attached to that benzene-group (K. J. Farrugia et al., 2011). This change in chemical structure occurs because hydrogen peroxide is broken down by hemoglobin. Because of that, the hemoglobin oxidizes the colorless ALCV into the purple state. This causes hemoglobin to be back in its original state again by a reduction reaction (see Figure 5) (BVDA, n.d.-c).

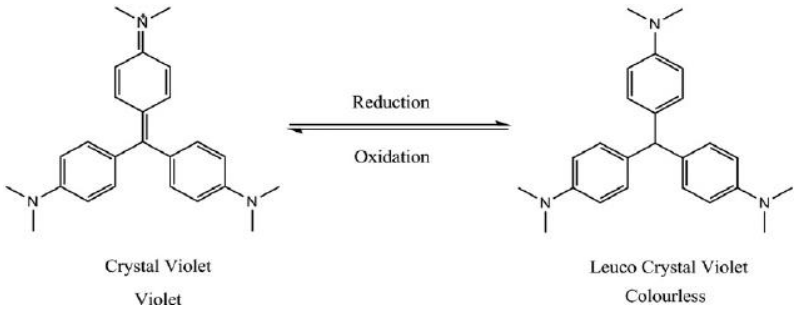

Figure 5; reaction ALCV with hemoglobin (K. J. Farrugia et al., 2011). By an oxidation reaction (reaction with hemoglobin), LCV turns from a colorless substance into a violet substance.

1.1.4.2. Hungarian Red (Fuchsin Red)

Hungarian Red (see Figure 4), also called Fuchsin Red or Acid Fuchsin, reacts with proteins in blood (Hartley & Glynn, 2017) and is mostly used for fingerprints or shoeprints placed in/with blood. Hungarian Red works best on non-porous, light colored, substrates (Girard, 2018). Since it reacts with proteins, it is more sensitive than the blood enhancement techniques based on peroxidase (like ALCV) because it will not only react with hemoglobin, but also with the

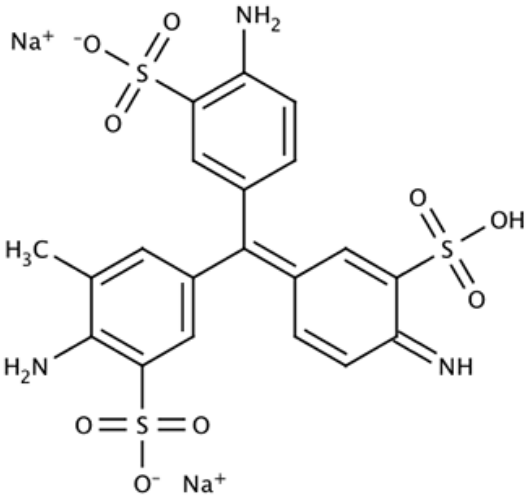

Figure 4; Hungarian Red (BVDA, n.d.-b). This image shows the chemical structure of Hungarian Red.

proteins (Ramotowski, 2012). Other examples of protein reagents are amido black, Coomassie blue, and acid yellow.

Before applying the Hungarian Red, the blood first has to be fixed to prevent leaching or diffusion of blood (K. J. Farrugia et al., 2011). This is carried out with a 2% sulfosalicylic acid. For ALCV, this 2% acid is already present in the ALCV-solution and therefore does not need a separate fixation step. Fixation with sulfosalicylic acid is based on the formation of insoluble salts/complexes and by disruption of the protein structure (J. James & Tas, 1984).

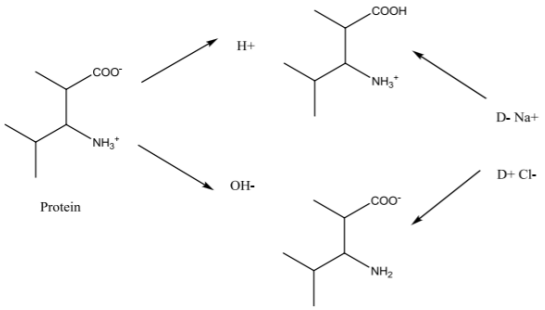

Figure 6; Hungarian Red (K. J. Farrugia et al., 2011). This figure shows the reaction of proteins in acidic environment.

The word acid in Acid Fuchsin does not refer to the acidity of the dye, but to the usage for dying. Acidic dyes possess colored anions (K. J. Farrugia et al., 2011). The SO_3^--groups of the acid dye assist the reaction by virtue of their negative charge (anion) (Holder & Laub, 2011). Under acidic conditions, the negative part of the protein (COO^-, see Figure 6,) reacts with the acid and forms a neutral part (COOH), which creates a net positive charge due to the NH_3^+ making it a cation (Holder & Laub, 2011). With this, the negative charged, colored anion can react. In addition, hydrogen bonding and other physical forces, e.g. van der Waals, also play a part in the affinity of acid dyes to protein molecules (Christie et al., 1999). The reaction of Hungarian Red with proteins produces a red-colored, fluorescent product (Ramotowski, 2012).

1.1.5. Color vision

Since one of the research questions is which color powder can be used best, the color vision of the human eye will be explained. The human eye contains cones, which are responsible for seeing colors. There are three kinds of cones; blue (S), green (M), and red (L) (Purves et al., 2001). However, there are not as much cones of every color; there are about 2% S-cones, 32% M-cones and 64% L-cones (Calkins, 2001). Because of that, the human eye is more sensitive to green and red, than to blue. Since yellow is in between the two most sensitive primary colors (red and green), most cones are 'activated' and therefore, yellow is seen as a bright color. This can also be seen in Figure 7. This figure shows the brightness of the three cone-colors (red (54), green (88), and blue (30)). Yellow is a combination of red and green, and therefore perceived as brighter. Cyan is a combination of green and blue, and since there are fewer blue cones than red cones, the brightness of cyan is less than that of yellow (Briggs, 2007). The brightness and complementary of colors influence how well colors, and in this case different fingerprint powder colors, are seen.

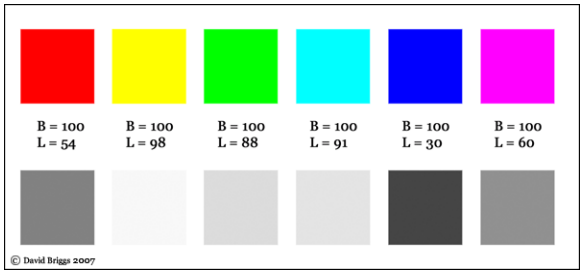

Figure 7; lightness colors (Briggs, 2007).. This figure shows that the colors in between the three cone-colors have a higher lightness than the three cone-colors.

1.2 Research questions

The research question belonging to this research is: Is it possible to enhance cyanoacrylate by using fingerprint powder instead of BY40? The sub questions all regard the variables/parameters described above, and are as follows:

- What is the optimal time between cyanoacrylate fuming and the enhancement?
    - What is the optimal time between cyanoacrylate fuming and powdering?

    - What is the optimal time between cyanoacrylate fuming and applying BY40?
- What is the effect of different concentrations BY40 on the resulting fingerprint?
- Is there a statistically significant difference between Lumicyano™, the enhancement with BY40, and the enhancement with the powders?
    - If so, which of the methods works best?
- Is lifting still possible with the different techniques?
    - For all three powders:
        - Is the lift better, similar, or worse than the original fingerprint?
        - Is the original fingerprint better, similar, or worse than the fingerprint that is left behind on the glass slide after lifting?
    - For BY40:
        - What gelatin lifter is best to use (a white or a black gelatin lifter)?
        - What is the optimal time to leave the gelatin lifter on the fingerprint (0, 5, 15, 30, or 60 minutes)?
        - Is the lift better, similar, or worse than the original fingerprint?
        - Is the original fingerprint better, similar, or worse than the fingerprint that is left behind on the glass slide after lifting?
- What powder can be used best on what surface material?
- Is it possible to enhance blood with Hungarian Red or ALCV after cyanoacrylate fuming and the different enhancement techniques?
    - In combination with what enhancement technique(s) is Hungarian Red possible?
    - In combination with what enhancement technique(s) is ALCV possible?

These sub questions are researched with the help of the materials and methods as described in *Methodology*. The results of the research are shown in *Results* and discussed in *Discussion and recommendations*. After that, conclusions are drawn in *Conclusion*.

2. Methodology

The aim of this research is to investigate whether enhancement of cyanoacrylate with powders is possible, instead of using BY40. Because of the complexity due to the amount of different variables, this research is divided into seven phases. The methodology of these seven phases is described in this chapter. The distribution of the samples can be found in *Appendix III – Distribution samples*. In these tables, D1 means a male donor, aged 53 years, D2 means a female donor, aged 22 years, and D3 means a female donor, aged 21 years. In addition to those samples, a negative control without a fingerprint was also used during each phase. All samples are photographed latent, after cyanoacrylate fuming, and after enhancement. The settings for those photos can be found in *Appendix IV – Settings camera*. The fingerprints are scored by ten raters (forensic sciences students) and the results are processed in Excel and IBM SPSS Statistics 25. For all results, a two-way random intraclass correlation with absolute agreement (ICC-test) is carried out to test whether the scores are reliable. Mann-Whitney U tests are carried out to test whether there are statistically significant differences. For these tests, the p-value is set at 0.05.

2.1. Chemicals

During this research, the following powders are used: green fluorescent powder (Loci Forensics B.V., Cat. No. 3005075, the Netherlands), orange fluorescent powder (Loci Forensics B.V., Cat. No. 3005073, the Netherlands), pink fluorescent powder (ArroSupranano, Cat. No. 01FRD060, UK), yellow fluorescent powder (Loci Forensics B.V. Cat. No. 3005074, the Netherlands), yellow magnetic powder (Sirchie, Cat. No. LL605, USA), and yellow powder in suspension (ArroSupranano, Cat. No. 03FYW250, UK). Cyanoacrylate (BVDA, Cat. No. B-83000, the Netherlands) and Lumicyano™ (Crime Science Technology, Cat. No. LK5-100, USA) were fumed in a cyanoacrylate fume hood (Air Science, Cat. No. SafeFume CA30S, USA), or a cyano-shot (Lynn Peavey, Cat. No. 06636, USA) was used. The BY40 (BVDA, Cat. No. B-85200, the Netherlands) was used in different dilutions (1:1, 1:8, or 1:18). The different surface materials used are aluminum (Praxis, Cat. No. 3047, the Netherlands), glass (Servoprax, Cat. No. D4 0301-E, Germany), plastic (Praxis, Cat. No. 1037, the Netherlands), and wood (Praxis, Cat. No. 2002, the Netherlands). Which one is used for each phase is described in the phases itself. Fingerprints were lifted with white (BVDA, Cat. No. B-14000, the Netherlands) or black gelatin lifters (BVDA, Cat. No. B-11000, the Netherlands). For the blood enhancement techniques, ALCV (BVDA, Cat. No. B-88600, the Netherlands) and Hungarian Red (BVDA, Cat. No. B-88000, the Netherlands) were used. The remainder of the materials used (ethanol, demineralized water, etc.) is presented in *Appendix II – Materials*.

2.2. Phase 1 – time-interval cyanoacrylate and enhancement

During the first phase, the optimal time-interval (0 or $\pm$24 hours) between cyanoacrylate fuming and the enhancement of the three different powders and BY40 is researched. These specific time-intervals are chosen so that it will be sure the cyanoacrylate is moisture (0 hours) or hardened (24 hours). Since BY40 is yellow, the other powders were also used in yellow, so that the contrast regarding the powder and the surface does not affect the results/scoring.

Figure 8; fingerprint will be placed in the middle of a glass slide.

First, forty (40) fingerprints were placed in the middle of two glass slides (see Figure 8) (so a total of eighty (80) glass slides) in a rolling motion (left to right); it is assumed that the two halves consist out of almost the same components. The next day, the samples were placed vertically in the cyanoacrylate fumehood with the following settings (see *Appendix I – Using the cyanoacrylate fume hood* how to use the cyanoacrylate fumehood):

- Amount of cyanoacrylate: 3.0 grams

- Time: 60 minutes
- Temperature hot plate: 130 °C
- Humidity: 80%

The left halves of the fingerprints were enhanced with the four different enhancement techniques within 35 minutes after cyanoacrylate fuming. The right halves of the fingerprints were enhanced ±24 hours after the cyanoacrylate fuming. Enhancement took place as follows. The glass slides were submerged in diluted BY40 (1:18 BY40:ethanol; 105 mg BY40 per liter ethanol) for fifty (50) seconds to distribute the BY40 evenly over the sample and to make sure that all samples are treated the same way. After that, the remainder was washed away by placing the sample in demineralized water for three seconds. The powder in suspension was applied by spraying a rich amount on the sample. After that, the remainder was removed by placing the sample in demineralized water for ten seconds. The fluorescent powder was applied with a continental squirrel hair brush. The magnetic powder was applied with a magnetic brush.

All samples were scored by ten forensic science students with the help of Table 1; *the grading system used for determining the quality of ridge detail for developed marks by Bandey and Gibson* (Bandey & Gibson, 2006). This grading system is developed and reported by researchers at the Centre of Applied Science and Technology (CAST) (Almog et al., 2014). The following tests were carried out to see whether there is a statistically significant difference between the different time-intervals per enhancement technique:

- BY40 0 hours // BY40 24 hours (Mann-Whitney U) (n=10)
- Fluorescent powder 0 hours // fluorescent powder 24 hours (Mann-Whitney U) (n=10)
- Magnetic powder 0 hours // magnetic powder 24 hours (Mann-Whitney U) (n=10)
- Powder in suspension 0 hours // powder in suspension 24 hours (Mann-Whitney U) (n=10)

Table 1; grading system for determining the quality of ridge detail for developed marks (Bandey & Gibson, 2006). With the help of this table, scores are given to the fingermarks by ten different participants.

Grade	Comments
0	No development
1	Signs of contact, but less than 1/3 of the mark contains continuous ridges
2	Between 1/3 and 2/3 of the mark contains continuous ridges
3	More than 2/3 of the mark contains continuous ridges, but not quite a perfect mark
4	Full development, whole mark clear, continuous ridges

2.3. Phase 2 – optimal concentration BY40

During the second phase, the optimal concentration of BY40 is researched. For this, BY40 was used in three different concentrations; 1000 milligrams BY40 per liter ethanol (dilution 1:1), 222 milligrams BY40 per liter ethanol (dilution 1:8), and 105 milligrams BY40 per liter ethanol (dilution 1:18).

First, thirty (30) fingerprints were placed on glass slides (so sixty (60) glass slides). The fingerprints were placed in the middle of two glass slides (see Figure 8). Since phase 1 showed that fingerprints placed in a rolling motion did not show nicely placed fingerprints in the middle of the glass slides, the fingerprints placed during this phase were placed without rolling. In addition, only the thumb was used since this finger is big enough to make a fingerprint big enough to work with, since it is placed in the middle of two glass slides. The next day, the samples were placed vertically in the cyanoacrylate fumehood with the same settings as used in phase 1.

The day after the cyanoacrylate fuming, the fingerprints were enhanced with the different concentrations of BY40. The fingerprints were placed for fifty (50) seconds in the different BY40 concentrations, and after that, placed in demineralized water for three seconds.

The fingerprints were scored with the help of Table 1. The following tests were carried out to see whether there is a statistically significant difference between the different concentrations of BY40:

- Dilution 1:1 // dilution 1:8 (Mann-Whitney U) (n=10)
- Dilution 1:1 // dilution 1:18 (Mann-Whitney U) (n=10)
- Dilution 1:8 // dilution 1:18 (Mann-Whitney U) (n=10)

2.4. Phase 3 – BY40 and Lumicyano™ vs powdering, third level features, and lifting

During the third phase, it is tested whether powdering of cyanoacrylate shows worse, similar, or better results than Lumicyano™ and cyanoacrylate enhanced with BY40. In addition, BY40 and Lumicyano™ are also compared. Again, yellow magnetic powder, fluorescent powder, and powder in suspension are used. For BY40, the 1:8 concentration was used. In addition, third level features, especially pores, and how well lifting is possible, got investigated.

Forty (40) fingerprints were placed on the glass slides as in phase 2 (according to Figure 8) (so eighty (80) glass slides). The next day, the samples were placed vertically in the cyanoacrylate fumehood with the same settings as used in phase 1. Sixty (60) of the samples were enhanced with cyanoacrylate and twenty (20) with Lumicyano™. The settings for the Lumicyano™ were as follows:

- Lumicyano™: 8% (215 milligrams powder in 2.7 grams solution)
- Time: 60 minutes
- Temperature hot plate: 120 ^{o}C
- Humidity: 80%

The samples fumed with cyanoacryate got enhanced after 24 hours. The fingerprints were scored with the help of Table 1. The following tests were carried out to see whether there is a statistically significant difference between Lumicyano™, enhancement with BY40, and enhancement with the three different powders:

- BY40 // fluorescent powder (Mann-Whitney U) (n=7)
- BY40 // magnetic powder (Mann-Whitney U) (n=7)
- BY40 // powder in suspension (Mann-Whitney U) (n=6)
- Lumicyano™ // fluorescent powder (Mann-Whitney U) (n=7)
- Lumicyano™ // magnetic powder (Mann-Whitney U) (n=7)
- Lumicyano™ // powder in suspension (Mann-Whitney U) (n=6)
- BY40 // Lumicyano™ (Mann-Whitney U) (n=20)

During this phase, third level features of the fingerprints were also investigated with the help of a microscope. For this, fingerprints were chosen with a high quality. During the investigation of the third level features, it was investigated how well pores were visible.

After the visual analysis, fifteen (15) fingerprints were lifted with a black gelatin lifter. A gelatin lifter was chosen since this is a lifter that is mostly used by the Dutch police, and since it is also possible to lift magnetic powder with this lifter (see also *Lifting fingerprints*). A statistical comparison was made between the initial fingerprints (on the glass slides) and the lifts (Mann-Whitney U test) and the fingerprint on the glass slide before and after lifting (Mann-Whitney U test).

2.5. Phase 4 – lifting BY40

During the fourth phase, it is tested whether lifting of BY40 is possible and what settings can be used best. The variables tested are the kind of lifter (white or black gelatin lifter) and the time the lifter was placed on the fingerprint (0, 5, 15, 30, and 60 minutes). For this, the BY40 with a concentration of 1:8 was used.

Forty (40) fingerprints were placed on the glass slides as in phase 2 (according to Figure 8) (so eighty (80) glass slides). The next day, the samples were placed vertically in the cyanoacrylate fumehood with the same settings as used in phase 1. 24 hours after that, the samples got enhanced with BY40. Two hours after the enhancement, black gelatin lifters were placed on the left side of the fingerprints and white gelatin lifters on the right side of the fingerprints. The filters were removed after 0, 5, 15, 30, or 60 minutes. After that, both the lifter as the remainder on the glass slide got photographed. The fingerprints got scored with the help of Table 1. The following tests were carried out to see what the best filter and optimal time are, whether lifting shows good results compared to the initial fingerprint, and whether the remainder of the fingerprint has the same quality as the fingerprint before lifting:

- Black gelatin lifter // white gelatin lifter. For this, the score of the lift – the score of the slide was taken. This way, a negative score means that the lift is worse than the initial fingerprint and a positive score means that the lift is better than the initial fingerprint. (Mann-Whitney U) (n=40)
- Per color lifter the different time-intervals. According to the same principle as the point above. (Mann-Whitney U) (n=8).
- Lift // initial slide (Mann-Whitney U) (n=40)
- Initial slide // slide after lifting (Mann-Whitney U) (n=40)

2.6. Phase 5 – surface materials

During the fifth phase, it is tested on which surface materials enhancement of cyanoacrylate with powders is possible, and which powder works best on which surface material. Again, yellow magnetic powder, fluorescent powder, and powder in suspension are used. The different surface materials are glass, aluminum, plastic, and wood (both painted with water-based paint and not painted). These surface materials are chosen since these are most common to be enhanced with cyanoacrylate (see *Appendix VIII – Interview Lauren Harder*)

First, two hundred (200) surfaces (forty (40) glass, forty (40) aluminum, forty (40) plastic, forty (40) wood not painted, and forty (40) wood painted) are cleaned with ethanol. After that, fingerprints were placed on the surface as in phase 2 (according to Figure 8). After 24 hours, the samples were placed vertically in the cyanoacrylate fumehood with the same settings as used in phase 1. After 24 hours, the enhancement took place.

The fingerprints were scored with the help of Table 1. The following tests were carried out to see whether there is a statistically significant difference between the different powders per surface material:

- Fluorescent powder // magnetic powder (Mann-Whitney U) (n=7)
- Fluorescent powder // powder in suspension (Mann-Whitney U) (n=7)
- Magnetic powder // powder in suspension (Mann-Whitney U) (n=6)

2.7. Phase 6 – colors

During the sixth phase, it is tested which powder color is visible best. For this, fluorescent powder in four different colors was used: orange, yellow, green, and pink. These colors are chosen since these are most commonly used by the Dutch police.

Forty (40) fingerprints were placed in the center of the glass slides (so not according to Figure 8) (so forty (40) glass slides). After 24 hours, the samples were placed vertically in the cyanoacrylate fumehood with the same settings as used in phase 1. After 24 hours, the enhancement took place.

This time, the samples were not scored with the help of Table 1; four fingerprints (each enhanced with a different color) were shown to the raters at the same time. The raters make a ranking: the powder color which is visible best gets four points, the powder color after that three points, the powder color after that two points, and the powder color that is visible worst got one point (so ten points in total). If the raters were unable to distinguish between two or more fingerprints, they could divide their ten points. However, they were not allowed to give a score lower than one or higher than four. Each fingerprint powder color can get an average score between one and four.

The following tests were carried out to see whether there is a statistically significant difference between the different powders:

- Yellow // green (Mann-Whitney U) (n=10)
- Yellow // orange (Mann-Whitney U) (n=10)
- Yellow // pink (Mann-Whitney U) (n=10)
- Green // orange (Mann-Whitney U) (n=10)
- Green // pink (Mann-Whitney U) (n=10)
- Orange // pink (Mann-Whitney U) (n=10)

2.8. Phase 7 – blood enhancement techniques

During the seventh phase, the effect of the different enhancement techniques of cyanoacrylate on blood enhancement techniques is researched. For this, cyanoacrylate enhanced with yellow magnetic powder, fluorescent powder, powder in suspension, and BY40 are used.

Thirty-two (32) fingerprints were placed on glass slides as in phase 2 (according to Figure 8) (so sixty-four (64) glass slides). However, two fingerprints were placed on each glass slide; one latent and one placed with blood. After 24 hours, the samples were placed vertically in the cyanoacrylate fumehood with the same settings as used in phase 1. Since the slides were not developed enough, the glass slides were placed in the fume hood again for 30 minutes with 1.5 grams cyanoacrylate. After 24 hours, the enhancement took place.

After all samples were enhanced, they were photographed. After that, a blood enhancement technique was applied: ALCV or Hungarian Red. These two techniques are chosen since one is a technique based on the reaction with hemoglobin and the other is based on the reaction with proteins and all the other blood enhancement techniques are also based on one of those two reactions. For ALCV, the fingerprint was submerged in ALCV for about one second (a fixator is present in ALCV). This process was repeated for each fingerprint until the fingerprint (placed in blood) did not change color anymore. For Hungarian Red, a fixation had to take place first. This was done by submerging the fingerprint in the fixation solution for 1.5 minute. After that, the fingerprint got submerged in Hungarian Red for 1.5 minute, then there was a 1.5 minute waiting time, and then the fingerprint got rinsed by placing it in demineralized water for about one second. For reasons explained in the results, these fingerprints did not get scored.

3. Results

The aim of this research is to investigate whether enhancement of cyanoacrylate with powders is possible, instead of using BY40. Therefore, the research is divided into seven phases, of which the results will be shown in this chapter.

First, ICC-tests were carried out per phase. The results of this are shown in Table 2. All ICC-values show a good or an excellent agreement (Koo & Li, 2016).

Table 2; ICC-values. This table shows the ICC-values for the different phases with their 95% confidence interval. All ICC-values have a good or excellent agreement.

	ICC-value	95% confidence interval	Agreement
Phase 1	0.912	0.876-0.940	Excellent
Phase 2	0.848	0.764-0.904	Good
Phase 3	0.897	0.843-0.942	Good
Phase 4	0.894	0.823-0.931	Good
Phase 5	0.948	0.920-0.965	Excellent
Phase 6	0.910	0.862-0.947	Excellent

3.1. Phase 1 – time-interval cyanoacrylate and enhancement

The aim of the first phase was to research what the optimal time-interval (0 or 24 hours) between cyanoacrylate fuming and the enhancement of the cyanoacrylate is. Figure 9 shows examples of each group; from top left to bottom right (in pairs): BY40, fluorescent powder, magnetic powder, and suspension. All left images are enhanced right after cyanoacrylate fuming and all right images were enhanced after 24 hours. Table 3 shows the averages and standard deviations of the different groups, and whether there is a statistically significant difference (S) between the groups or not (NS). As can be seen in this table, there is a statistically significant difference (S) between the enhancement of fluorescent powder and BY40 between the two different time-intervals; for both enhancement techniques, a better score is gained after 24 hours. For powder in suspension and magnetic powder, there was no statistically significant difference between the scores of 0 and 24 hours.

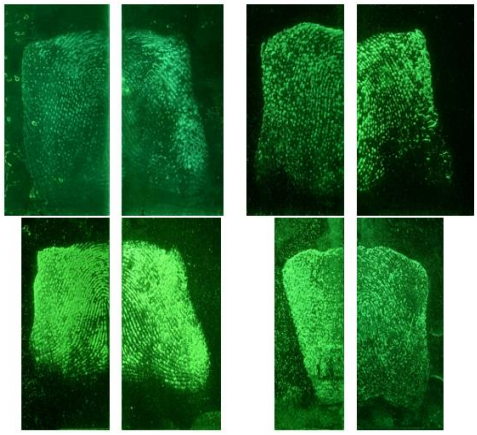

Figure 9; fingerprints phase 1. From top left to bottom right: BY40, fluorescent, magnetic, and suspension. All the left images are enhanced after 0 hours and all the right images are enhanced after 24 hours.

Table 3; results phase 1 – optimal time-interval. There is a statistically significant difference (S) between fluorescent powder 0 hours and fluorescent powder 24 hours, and BY40 0 hours and BY40 24 hours. In both cases, enhancement after 24 hours gives a higher score. For powder in suspension and magnetic powder, there was no statistically significant difference (NS) between the two different time-intervals.

Group	Average (SD)	Stat. sign. difference ($p \leq 0.05$) (S = stat. sign. difference, NS = no stat. sign. difference)
Fluorescent powder, 0 hours	1.28 ($\pm$0.54)	S
Fluorescent powder, 24 hours	1.84 ($\pm$0.56)	
Powder in suspension, 0 hours	2.20 ($\pm$0.88)	NS
Powder in suspension, 24 hours	2.14 ($\pm$0.48)	
Magnetic powder, 0 hours	1.82 ($\pm$0.80)	NS
Magnetic powder, 24 hours	1.81 ($\pm$0.65)	
BY40, 0 hours	1.32 ($\pm$0.57)	S
BY40, 24 hours	2.04 ($\pm$0.75)	

3.2. Phase 2 – concentration BY40

The aim of the second phase was to test what concentration of BY40 can be used best to enhance cyanoacrylate. Figure 10 shows examples of each concentration; from left to right: 1:1, 1:8, and 1:18. Table 4 shows the averages and standard deviations of each group, and whether there is a statistically significant difference (S) between the groups or not (NS). As can be seen in this table, there are no statistically significant differences (NS) between the different dilutions.

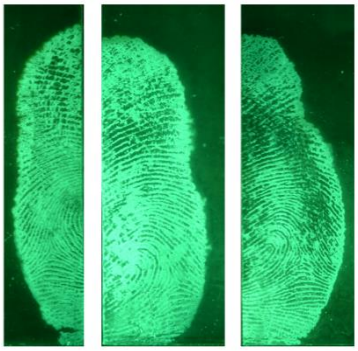

Figure 10; fingerprints phase 2. From left to right: concentration BY40 1:1, 1:8 and 1:18.

Table 4; results phase 2 – concentration BY40. There is no statistically significant difference (NS) between the different concentrations of BY40.

Group	Average (SD)	Stat. sign. difference ($p \leq 0.05$) (S = stat. sign. difference, NS = no stat. sign. difference)
Dilution 1:1	2.25 ($\pm$0.54)	NS
Dilution 1:8	1.95 ($\pm$0.63)	
Dilution 1:1	2.21 ($\pm$0.63)	NS
Dilution 1:18	2.28 ($\pm$0.52)	
Dilution 1:8	2.14 ($\pm$0.79)	NS
Dilution 1:18	1.97 ($\pm$0.71)	

3.3. Phase 3 – BY40 and Lumicyano™ vs powdering, third level features, and lifting

The aim of the third phase was to investigate whether enhancement of cyanoacrylate with powders gives better, similar, or worse results than enhancement with BY40 and Lumicyano™. In addition, for all techniques, it was also investigated whether third level features were usable (especially pores) and whether lifting is possible.

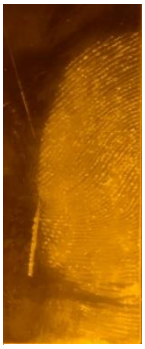

Figure 11; fingerprint with Lumicyano™.

3.3.1. BY40 and Lumicyano™ vs powdering

The results of this part of the phase are presented in Table 5. This table shows the averages and standard deviations of the different groups, and whether there is a statistically significant difference (S) between the groups or not (NS). The table shows that there is no statistically significant difference (NS) between the enhancement with

BY40 and the enhancement with the three different powders. In addition, there is also no statistically significant difference (NS) between Lumicyano™ and fluorescent powder, and Lumicyano™ and magnetic powder. However, there is a statistically significant difference (S) between Lumicyano™ and powder in suspension, and Lumicyano™ and BY40. In both cases, Lumicyano™ has a higher score.

Table 5; results phase 3 – BY40 and Lumicyano™ vs powdering. There is a statistically significant difference (S) between Lumicyano™ and powder in suspension, and Lumicyano™ and BY40; in both cases Lumicyano™ has a higher score. There is no statistically significant difference (NS) between the other groups.

Group	Average (SD)	Stat. sign. difference ($p \leq 0.05$) (S = stat. sign. difference, NS = no stat. sign. difference)
BY40	2.36 (±0.42)	NS
Fluorescent powder	2.26 (±0.63)	
BY40	1.53 (±0.63)	NS
Magnetic powder	1.91 (±0.46)	
BY40	2.07 (±0.78)	NS
Powder in suspension	1.72 (±0.70)	
Lumicyano™	2.12 (±0.66)	NS
Fluorescent powder	2.00 (±0.37)	
Lumicyano™	2.71 (±0.48)	NS
Magnetic powder	2.06 (±0.82)	
Lumicyano™	2.92 (±0.40)	S
Powder in suspension	1.55 (±0.84)	
Lumicyano™	2.57 (±0.63)	S
BY40	1.98 (±0.71)	

3.3.2. Third level features

The third level features of the three different donors were investigated. However, after cyanoacrylate fuming, it was already seen that the ridges were dense due to the amount of cyanoacrylate (see Figure 13); third level features are not useable after regular cyanoacrylate fuming.

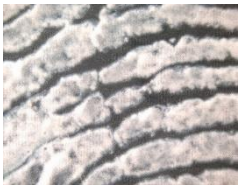

Figure 13; cyanoacrylate makes the use of third level features (pores) not possible.

3.3.3. Lifting

During this part of phase 3, the possibility of lifting the powder used to enhance cyanoacrylate and what the effect of the lifting is on the original fingerprint was also researched. Table 6 shows that there is a statistically significant difference (S) between the original fingerprint and the lift of fluorescent powder and magnetic powder. In both cases, the original fingerprint has a higher score than the lift. For powder in suspension, there was no statistically significant difference (NS). Table 7 shows that there is no statistically significant difference (NS) between the fingerprint before and after lifting for all three powders.

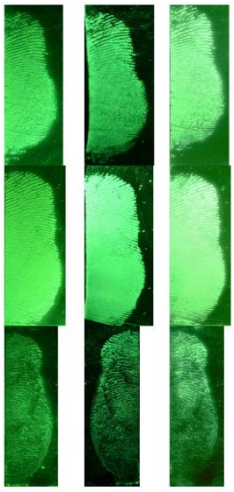

Figure 12; fingerprint phase 3. From left to right: original fingerprint, lift, and fingerprint after lifting. From top to bottom: fluorescent powder, magnetic powder, suspension.

Table 6; results lifting phase 3, comparison original fingerprint and lift. This table shows that there is a statistically significant difference (S) between the original fingerprint and the lift of fluorescent powder and magnetic powder. In both cases, the original fingerprint has a higher score. For powder in suspension, there is no statistically significant difference (NS).

Group	Average (SD)	Stat. sign. difference ($p \leq 0.05$) (S = stat. sign. difference, NS = no stat. sign. difference)
Fluorescent powder, original fingerprint	2.60 ($\pm$0.33)	S
Fluorescent powder, lift	1.68 ($\pm$0.40)	
Magnetic powder, original fingerprint	2.48 ($\pm$0.62)	S
Magnetic powder, lift	1.46 ($\pm$0.19)	
Powder in suspension, original fingerprint	2.14 ($\pm$0.87)	NS
Powder in suspension, lift	1.94 ($\pm$0.88)	

Table 7; results lifting phase 3, comparison fingerprint before and after lifting. This table shows that there is no statistically significant difference (NS) between the fingerprint before and after lifting for all three powders.

Group	Average (SD)	Stat. sign. difference ($p \leq 0.05$) (S = stat. sign. difference, NS = no stat. sign. difference)
Fluorescent powder, original fingerprint	2.60 ($\pm$0.33)	NS
Fluorescent powder, after lifting	2.54 ($\pm$0.34)	
Magnetic powder, original fingerprint	2.48 ($\pm$0.62)	NS
Magnetic powder, after lifting	2.42 ($\pm$0.89)	
Powder in suspension, original fingerprint	2.14 ($\pm$0.87)	NS
Powder in suspension, after lifting	1.88 ($\pm$0.89)	

3.4. Phase 4 – lifting BY40

The aim of the fourth phase was to investigate whether lifting of BY40 is possible, and if so, which settings can be used best. An example of lifts with BY40 with both a white and black gelatin lifter is shown in Figure 14. First, it was tested which of the two lifters (black or white gelatin lifter) shows the best scores. For this, the score of the slide is subtracted by the score of the score of the lift, since the average score of the lifts is not the same for all time intervals. Therefore, a negative score means the lift is worse than the original fingerprint and a positive score means the lift is better than the original fingerprint. This data is presented in Table 8 and shows the average scores and standard deviation of the different lifters per time interval, and in total. A Mann-Whitney U test showed that there is a statistically significant difference (S) between the white and black gelatin lifter; the gelatin lifter has a higher average.

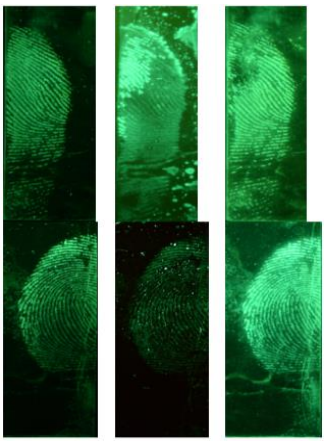

Figure 14; lifting BY40. Upper images: lifting BY40 with a white gelatin lifter. Lower images: lifting BY40 with a black gelatin lifter. Left to right: original fingerprint (after BY40), lift with BY40, original fingerprint after lifting.

The next step was to see which time interval shows the best results. The results for this are presented in Table 9 (black gelatin lifter) and Table 10 (white gelatin lifter). These tables show that for the black gelatin lifter, there is a statistically significant difference (S) between 0 and 60 minutes, and 5 and 60 minutes. Between the remainder of the time-intervals, there is no statistically significant difference (NS). For the white gelatin lifter, there is no statistically significant difference (NS) at all.

Table 8; results phase 4 – time-interval black and white gelatin lifter. For the black gelatin lifter, the longer the lift is placed on the fingerprint, the higher the score. For the white gelatin lifter, there is no correlation.

	Black gelatin lifter	**White gelatin lifter**
0 minutes	-0.58 (±0.46)	-0.63 (±0.40)
5 minutes	-0.56 (±0.46)	-0.63 (±0.40)
15 minutes	-0.21 (±0.43)	-0.91 (±0.44)
30 minutes	-0.21 (±0.31)	-0.80 (±0.25)
60 minutes	0.050 (±0.19)	-0.88 (±0.40)
Total	**-0.30 (±0.37)**	**-0.77 (±0.38)**

Table 9; results Mann-Whitney U tests time-interval black gelatin lifter. There is a statistically significant difference (S) between 0 and 60 minutes, and 5 and 60 minutes of the black gelatin lifter. Between the other time-intervals, there is no statistically significant difference (NS).

	0 minutes	**5 minutes**	**15 minutes**	**30 minutes**	**60 minutes**
0 minutes					
5 minutes	NS				
15 minutes	NS	NS			
30 minutes	NS	NS	NS		
60 minutes	S	S	NS	NS	

Table 10; results Mann-Whitney U tests time-interval white gelatin lifter. There is no statistically significant difference (NS) between the different time-intervals of the white gelatin lifter.

	0 minutes	**5 minutes**	**15 minutes**	**30 minutes**	**60 minutes**
0 minutes					
5 minutes	NS				
15 minutes	NS	NS			
30 minutes	NS	NS	NS		
60 minutes	NS	NS	NS	NS	

During this research, it was also tested whether the lift shows better, similar, or worse results than the original fingerprint. The results of the black gelatin lifter are shown in Table 11 and of the white gelatin lifter in Table 12. Table 11 shows that there is no statistically significant difference (NS) between the original fingerprint and the lift for the black gelatin lifter. For the white gelatin lifter, at every time-interval besides 15 minutes, there is a statistically significant difference (S), at which the original fingerprint has a higher score than the lift.

Table 11; results original fingerprint vs lift, black gelatin lifter. There are no statistically significant differences (NS) between the original fingerprint and the lift.

	Score original fingerprint	**Score lift**	**Mann-Whitney U test**
0 minutes	2.25 (±0.74)	2.01 (±0.47)	NS
5 minutes	2.14 (±0.73)	1.94 (±0.57)	NS
15 minutes	2.48 (±0.54)	2.26 (±0.60)	NS
30 minutes	2.21 (±0.90)	2.00 (±0.68)	NS
60 minutes	2.13 (±0.92)	2.18 (±1.02)	NS

Table 12; results original fingerprint vs lift, white gelatin lifter. This table shows that there is a statistically significant difference (s) at all time-intervals between the original fingerprint and the lift, besides the time-interval of 15 minutes (NS). In all cases, the score of the original fingerprint is higher than the score of the lift.

	Score original fingerprint	**Score lift**	**Mann-Whitney U test**
0 minutes	2.26 (±0.84)	1.33 (±0.72)	S
5 minutes	2.25 (±0.71)	1.35 (±0.53)	S
15 minutes	2.09 (±0.84)	1.18 (±0.45)	NS
30 minutes	2.09 (±0.70)	1.29 (±0.54)	S
60 minutes	2.08 (±0.64)	1.23 (±0.56)	S

During this research, it was also tested whether lifting causes damage to the original fingerprint by comparing the scores of the original fingerprint before and after lifting. These results are shown in Table 13 for the black gelatin lifter and in Table 14 for the white gelatin lifter. Both tables show that there is no statistically significant difference (NS) between the fingerprints before and after lifting, for both the white and the black gelatin lifter.

Table 13; results fingerprints before and after lifting, black gelatin lifter. This table shows that there is no statistically significant difference (NS) at all time-intervals between the fingerprints before and after lifting.

	Score original fingerprint	**Score lift**	**Mann-Whitney U test**
0 minutes	2.25 (±0.74)	2.24 (±0.62)	NS
5 minutes	2.14 (±0.73)	2.30 (±0.76)	NS
15 minutes	2.48 (±0.54)	2.58 (±0.55)	NS
30 minutes	2.21 (±0.90)	2.10 (±0.90)	NS
60 minutes	2.13 (±0.92)	2.18 (±0.90)	NS

Table 14; results fingerprints before and after lifting, white gelatin lifter. This table shows that there is no statistically significant difference (NS) at all time-intervals between the fingerprints before and after lifting.

	Score original fingerprint	**Score lift**	**Mann-Whitney U test**
0 minutes	2.26 (±0.84)	1.98 (±0.68)	NS
5 minutes	2.25 (±0.71)	2.16 (±0.82)	NS
15 minutes	2.09 (±0.84)	2.08 (±0.67)	NS
30 minutes	2.09 (±0.70)	1.99 (±0.50)	NS
60 minutes	2.08 (±0.64)	2.08 (±0.72)	NS

3.5. Phase 5 – surface materials

The aim of the fifth phase was to investigate what powder can be used best on what surface material (glass, plastic, aluminum, wood painted, and wood not painted). An example of the three different powders on the different surface materials is shown in Figure 15.

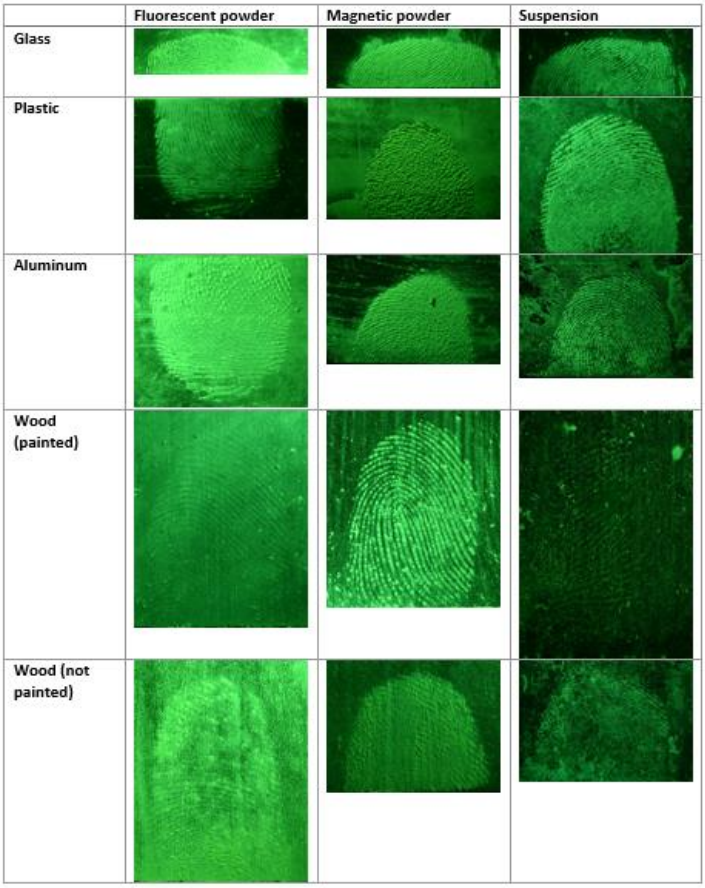

Figure 15; surface materials. From left to right: fluorescent powder, magnetic powder, and suspension. From top to bottom: glass, plastic, aluminum, wood (painted), and wood (not painted).

The results (averages, standard deviations, and results of the Mann-Whitney U tests) of all different surface materials are presented in Table 15. For glass, there is no statistically significant difference (NS) between the three different powders. For plastic, there is only a statistically significant difference (S) between fluorescent powder and powder in suspension, at which fluorescent powder has a higher score. Between the other powders, there is no statistically significant difference (NS). Of aluminum, there is also only a statistically significant difference (S) between fluorescent powder and powder in suspension. However, at aluminum, powder in suspension has a higher score than fluorescent powder. Between the other powders, there is no statistically significant difference (NS). For painted wood, there is a statistically significant difference (S) between powder in suspension and magnetic powder at which magnetic powder has a higher score. Between the other powders, there is no statistically significant difference (NS). For not painted wood, there is a statistically significant difference (S) between powder in suspension and magnetic powder, and powder in suspension and fluorescent powder; powder in suspension has a lower score than magnetic powder and fluorescent powder. Between magnetic powder and fluorescent powder, there is no statistically significant difference (NS).

Table 15; results phase 5 – surface materials. For glass, there is no statistically significant difference (NS) between the different powders. For plastic, there is a statistically significant difference (S) between fluorescent powder and powder in suspension at which fluorescent powder has a higher score. For aluminum, there is a statistically significant difference (S) between fluorescent powder and powder in suspension at which powder in suspension has a higher score. For painted wood, there is a statistically significant difference (S) between magnetic powder and powder in suspension at which magnetic powder has a higher score. At non-painted wood, there is a statistically significant difference (S) between fluorescent powder and powder in suspension, and magnetic powder and powder in suspension, at which suspension has a lower score in both cases. Between all the other powders per surface material, there are no statistically significant differences (NS).

Group	**Average (SD)**	**Stat. sign. difference ($p \leq 0.05$) (S = stat. sign. difference, NS = no stat. sign. difference)**
Glass, fluorescent powder	2.00 ($\pm$0.89)	NS
Glass, magnetic powder	2.11 ($\pm$0.69)	
Glass, fluorescent powder	2.29 ($\pm$0.35)	NS
Glass, powder in suspension	2.03 ($\pm$0.51)	
Glass, magnetic powder	1.45 ($\pm$0.51)	NS
Glass, powder in suspension	1.70 ($\pm$0.78)	
Plastic, fluorescent powder	2.00 ($\pm$0.71)	NS
Plastic, magnetic powder	1.36 ($\pm$0.66)	
Plastic, fluorescent powder	2.17 ($\pm$0.52)	S
Plastic, powder in suspension	1.23 ($\pm$0.81)	
Plastic, magnetic powder	1.37 ($\pm$0.59)	NS
Plastic, powder in suspension	0.95 ($\pm$0.79)	
Aluminum, fluorescent powder	1.56 ($\pm$0.51)	NS
Aluminum, magnetic powder	1.60 ($\pm$0.49)	
Aluminum, fluorescent powder	1.16 ($\pm$0.53)	S
Aluminum, powder in suspension	1.89 ($\pm$0.78)	
Aluminum, magnetic powder	1.08 ($\pm$0.31)	NS
Aluminum, powder in suspension	1.63 ($\pm$0.93)	
Painted wood, fluorescent powder	0.83 ($\pm$0.76)	NS
Painted wood, magnetic powder	1.13 ($\pm$0.75)	
Painted wood, fluorescent powder	0.31 ($\pm$0.28)	NS
Painted wood, powder in suspension	0.06 ($\pm$0.073)	
Painted wood, magnetic powder	1.73 ($\pm$1.28)	S
Painted wood, powder in suspension	0.13 ($\pm$0.41)	
Not painted wood, fluorescent powder	0.76 ($\pm$0.32)	NS
Not painted wood, magnetic powder	0.81 ($\pm$0.27)	
Not painted wood, fluorescent powder	0.91 ($\pm$0.36)	S
Not painted wood, powder in suspension	0.27 ($\pm$0.43)	
Not painted wood, magnetic powder	0.73 ($\pm$0.31)	S
Not painted wood, powder in suspension	0.15 ($\pm$0.21)	

3.6. Phase 6 – colors

The aim of the sixth phase was to research which color powder can be used best to enhance cyanoacrylate. An example of all fingerprint colors is shown in Figure 16, both with and without light sources. The average scores and standard deviation per color are given in Table 16. The results of the Mann-Whitney U test are given in Table 17. This table shows that there is a statistically significant difference (S) between the pink powder and the other three powder colors. In all cases, the pink powder has a lower score than the other powders. Between the three remaining powder colors, there are no statistically significant differences (NS).

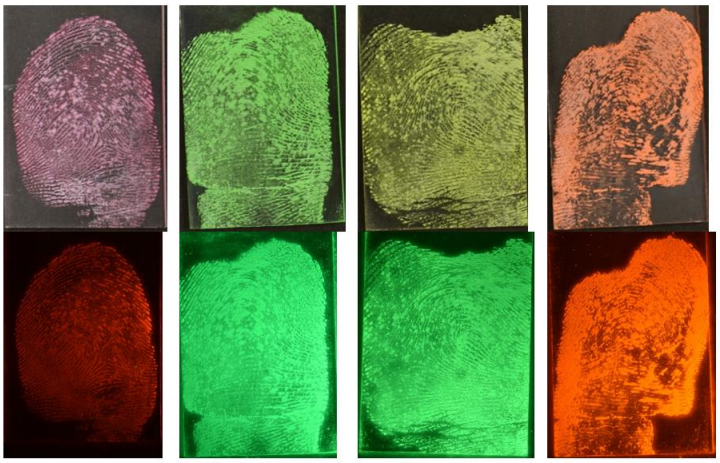

Figure 16; different colors fingerprint powder. Upper from left to right: pink powder, green powder, yellow powder, and orange powder. At the bottom, the same fingerprints are shown. However, these fluorescent due to the use of light sources.

Table 16; phase 6 – colors. This table shows the average scores and standard deviations of the different powder colors.

	Average (SD)
Pink	1.27 ($\pm$0.22)
Yellow	2.91 ($\pm$0.53)
Green	2.75 ($\pm$0.36)
Orange	3.07 ($\pm$0.43)

Table 17; Mann-Whitney U test phase 3 – colors. This table shows that there are statistically significant differences (S) between the pink powder and all the other powders. Between all the other powders, there are no statistically significant differences (NS).

	Pink	**Yellow**	**Green**	**Orange**
Pink				
Yellow	S			
Green	S	NS		
Orange	S	NS	NS	

3.7. Phase 7 – blood enhancement techniques

The aim of the seventh phase was to test whether blood enhancement techniques were still possible after enhancing cyanoacrylate with powders or BY40. However, all samples showed none or hardly any result to the blood enhancement techniques. For ALCV, there was some reaction with the blood, but the resulting fingerprint was not usable (top left, Figure 17). Some of the samples enhanced with ALCV also showed no reaction (top right, Figure 17). For Hungarian Red, 29 out of 32 fingerprints showed no reaction (bottom right, Figure 17). The other three showed a reaction, but only a small amount of the fingerprint got enhanced (bottom left, Figure 17).

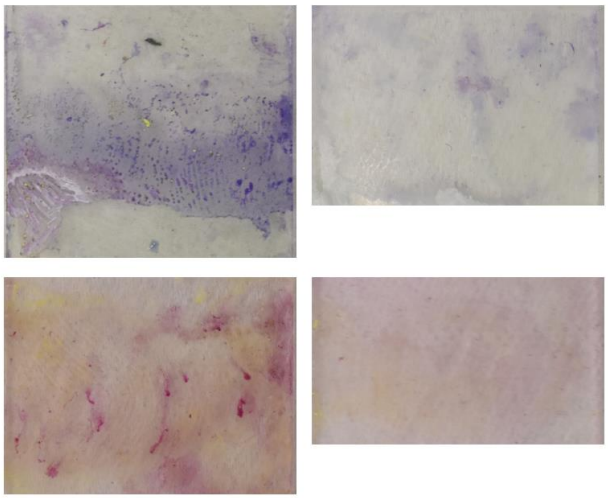

Figure 17; blood enhancement techniques. From top left to bottom right: ALCV positive result, ALCV negative result, Hungarian Red positive result, and Hungarian Red negative result.

4. Discussion and recommendations

The aim of this research is to investigate whether enhancement of cyanoacrylate with powders is possible, instead of enhancement with BY40. The reason for this is that BY40 is toxic and a liquid, and it is therefore assumed that this is damaging to other traces and DNA (Netherlands Forensic Institute, 2018). The use of BY40 is also hazardous for both the People aspect as the Planet aspect of durability. For People this has two reasons. The first reason is that the ethanol is hazardous for the health of the user. The second reason is that the process of applying BY40 washes away DNA, making the chance of catching a perpetrator smaller.

Fingerprints of three different donors were taken. For this, donors of both sexes and differing ages were chosen. In addition, one of the donors developed fingerprints of a worse quality than the other two donors. Taking these factors into consideration, it can be stated that the sample consists out of a varying group and is randomly chosen. For validation, the first tests are also mostly carried out with three to five donors. Even though this is not representative of reality, it provides a starting point (Almog et al., 2014). One of the recommendations is to use more donors for further research/validation.

A Mann-Whitney U test was chosen since it is assumed that the data is not normally distributed. This assumption was made since, if there is a statistically significant difference between two groups, it is not possible that both groups have data that is normally distributed; a shift in data must take place, otherwise there cannot be a statistically significant difference. However, the Mann-Whitney U test has a smaller power than a t-test (which assumed normally distributed data). The smaller the power, the smaller the chance that a certain difference is perceived in a group. Therefore, there is a bigger change that H_0 is accepted while this is not the case; type II error. A type II error can be prevented by increasing the level of significance to, for example, 10%. However, this increases the chance of a type I error. Therefore, it is decided to set the level of significance at 5%. However, this is debatable.

During this research, it was chosen to use ethanol-based BY40 since this is currently used by the Dutch police. Methanol-based BY40 also exists. However, this is even more toxic to the user, the environment, and even the traces and is therefore not used. This research is divided into seven phases, which will be discussed in this chapter.

During the first phase of this study, the optimal time-interval (0 or 24 hours) between cyanoacrylate fuming and the enhancement with the different techniques (fluorescent powder, magnetic powder, powder in suspension, and BY40) was researched. This showed that the enhancement with fluorescent powder and BY40 gave better results after 24 hours. The enhancement with magnetic powder and powder in suspension showed no statistically significant difference. Beforehand, it was expected that the powder in suspension and BY40 would give better results after 24 hours, since those techniques contain liquids which might wash away the cyanoacrylate. On the other hand, it was expected that the magnetic powder and fluorescent powder would give better results after 0 hours, since the cyanoacrylate would still be moisture at that moment, and therefore, the powder would stick to the cyanoacrylate better (as described in *Physical methods*, fourth point). For BY40, the expectations were met. However, for the others, this was not the case. A possible explanation for the fluorescent powder giving better results after 24 hours, might be that the fingerprint will be wiped away by the brush if the powder is applied right after cyanoacrylate fuming. An explanation about why there is no difference for magnetic powder and powder in suspension was not found.

During the second phase of this study, the optimal concentration of BY40 is researched. This showed that there is no statistically significant difference between the different concentrations used. BY40 is mostly diluted if background noise is expected. During this study, hardly any background noise was observed, since the surfaces were cleaned before use. However, in real cases, the surface is not

cleaned before deposition of a fingerprint. Because of that, it might be that in real cases, a lower concentration might work best, since the resulting fingerprint will be the same, but there will be less background noise than with a higher concentration. For concentrations that are diluted in a higher extent than 1:18, additional research must be carried out. Being able the dilute BY40 will decrease the costs for using BY40, which is beneficial for the Profit aspect of durability.

During the third phase of this study, it was tested whether enhancing cyanoacrylate with fingerprint powders gives better, similar, or worse results than enhancement with BY40 and Lumicyano™. In addition, the usability of third level features and the possibility of lifting the powder was researched. This phase showed that there is no statistically significant difference between BY40 and the three powders. By looking at the results of phase 1, this was also expected, since the Mann-Whitney U tests between BY40 and the three powders of phase 1 also showed that there is no statistically significant difference between BY40 and the three powders.

In addition, there was a statistically significant difference between Lumicyano™ and powder in suspension, and Lumicyano™ and BY40. In both cases, Lumicyano™ has a higher score than BY40 or powder in suspension. No expectations were made regarding Lumicyano™ since the current literature differs quite a lot (see Luminescent cyanoacrylate). An explanation given for these different results in the current literature might come because if the settings in the manual are used, no luminescence took place. During this study, the fuming time had to be increased to 60 minutes instead of 25 which was stated in the manual to get a result. In addition, as can be seen in Figure 11, the fingerprint shows some places where more luminescence takes place (e.g. around the core) than other places. However, the remainder of the fingerprint is visible but did not luminesce. This might come due to luminescence quenching (Chadwick et al., 2014). Therefore, chances are high, that the fingerprint is scored quite high while only a small part of the fingerprint shows good luminescence.

During this phase, the use of third level features (especially pores) is also researched. However, quite soon, this showed that no pores were visible because the cyanoacrylate was quite dense. Therefore, no further research regarding third level features was carried out. Recent studies have shown that third level features will be visible if vacuum cyanoacrylate fuming is used, since fingerprints are mostly less dense using this instead of normal cyanoacrylate fuming (K. Farrugia et al., 2014).

In addition, the possibility of lifting the powder was also researched. The lifts of fluorescent powder and magnetic powder showed a statistically significant difference between the original fingerprint and the lift. In both cases, the original fingerprint had a higher score than the lift. For powder in suspension, there was no statistically significant difference between the original fingerprint and the lift. In addition, there was no statistically significant differences for all powders, between the original fingerprint before and after lifting; lifting did not damage or improve the original fingerprint.

During the fourth phase, the possibility of lifting BY40 was researched. The only information that was found so far about the lifting of BY40 came from the BVDA, which states *'The black Gellifters can be used to lift fingerprints which are developed with cyanoacrylate. These lifters are a last resort where: a developed fingerprint is stained with a staining solution […].'* (BVDA, n.d.-a). It was therefore expected that the black gelatin lifter would show the best results, which turned out to be true. However, no information was found about the time the lifter should be placed on the fingerprint. Because of that, no expectations were made regarding the time-interval. In addition, there were also no expectations about whether the lifts would be as good as the original fingerprint and whether it would cause damage to the fingerprint. Since lifting of BY40 currently does not take place, the expectations were not too high. However, the opposite turned out to be true; lifting of BY40 is possible without damaging the original fingerprint, and the quality of the lift is similar to the quality of the original fingerprint, for

the black gelatin lifter. The time-interval of the black gelatin lifter showed a statistically significant difference between 0 and 60 minutes, and 5 and 60 minutes. In both cases, the score at 60 minutes was higher. Furthermore, there were no statistically significant differences between the time-intervals. The benefit of being able to lift BY40 takes place when for example a fingerprint is made visible with BY40 on a fluorescent surface or when a fingerprint is placed on a surface that is not flat; by lifting it, it will be flat on the lifter. By comparing the results of lifting of BY40 to the results of lifting powders from phase 3, it can be seen that for all four enhancement techniques, no damage is caused to the original fingerprint. However, only the fingerprints enhanced with BY40 and powder in suspension show no statistically significant difference between the original fingerprint and the lift. For magnetic powder and fluorescent powder, there is a statistically significant difference at which, for both powders, the lift has a lower score than the original fingerprint.

During the fifth phase, it was tested with which powder enhancement of cyanoacrylate takes place best on different surface materials. Little information was found regarding the enhancement of cyanoacrylate with powders on different surface materials. For glass, it was expected that all powders could be used since glass is one of the easiest surface materials to work with. This also turned out to be true; there was no statistically significant difference between the different powders. For plastic, it was expected that fluorescent powder would work worse than magnetic powder and suspension. This, because fluorescent powder is applied with a squirrel hair brush which, in contrary to applying magnetic powder and suspension, touches the plastic. This causes, in cases without using cyanoacrylate, static electricity, and because of that, the small parts in between the fingerprint also get enhanced. This causes the fingerprint to be dense and therefore it is not possible anymore to distinguish between the ridges of the fingerprint. This is also described in *Physical methods*, third point. However, this research showed that fluorescent powder works better than fluorescent powder to enhance cyanoacrylate on plastic. Apparently, the cyanoacrylate lowers the electrostatic charge of the surface. There was no statistically significant difference between fluorescent powder and magnetic powder, and magnetic powder and powder in suspension. For aluminum, there was a statistically significant between fluorescent powder and powder in suspension, at which powder in suspension has a higher score. For fluorescent powder, the ridges became too dense which caused that no distinction could be made between the ridges, resulting in a lower score. This is not the fact for the suspension, probably due to the fact that the remainder of the powder that got stuck in between the ridges was washed away by the washing step. For painted wood, suspension worked worse than magnetic powder, and for not painted wood, suspension worked worse for both fluorescent powder and magnetic powder. The amount of cyanoacrylate that was bound to the fingerprints placed on wood, was minimal. This probably takes place because the wood is (semi-)porous. The wood being (semi-)porous might also be the problem for suspension.

In addition, to the fifth phase, it was also noticed that even though it was shown that some powders work better than others, there are still some differences between the surface materials. For example, the scores of the best powders to enhance wood are lower than the scores of the best powder to enhance plastic; respectively 0.31-1.73 for painted wood, 0.73-0.91 for not painted wood, and 2.00-2.17 for plastic. Therefore, it can not only be said which powder works best on which surface material, but also that the enhancement technique with powders works better on certain surface materials than on others.

During the sixth phase of this study, the optimal color (pink, orange, yellow or green) was researched. This showed that the pink powder showed a statistically significant worse result than the other powders. Between the other powders, there was no statistically significant difference. Since a light source with accompanying filter was used (yellow filter for yellow and green and a light orange filter

for pink and orange), it was expected that the ones with the yellow filter would be visible worse than the ones with the orange filters. Within the ones with the yellow filter (yellow and green powder), the green powder looked bluer and the yellow powder looked greener. Therefore, it was expected that the yellow powder would have a score that is a little higher than the green powder. For the pink and the orange powder, the pink powder looked red and the orange powder looked orange. It was therefore expected that red would have a higher score than orange. Concluding, the following order was expected (from worst to best): green, yellow, orange, pink. The order that came out of the results was: pink, green, yellow, orange. This shows, that the order of green, yellow and orange is as expected. However, the pink powder shows the worse results, which was expected to be showing the best results. For this, there might be an explanation; the pink powder was of the brand ArroSupranano and all the other powders were from Loci Forensics B.V. The pink powder showing less fluorescence than the other powders might come because it is from a different brand.

During the seventh phase of this study, the possibility of using blood enhancement techniques after enhancing cyanoacrylate with different methods was researched. This showed that the blood enhanced with ALCV did show a reaction, but none of these fingerprints were usable since the minimum amount of blood that reacted. For Hungarian Red, only three out of 32 fingerprints placed with blood reacted. Because of this, some additional tests were carried out to test what might cause those bad reactions. First, fingerprints in blood were placed in the cyanoacrylate fume hood without cyanoacrylate, to test whether the heat of the heating plate might cause a reaction that caused the blood not to react anymore. This test showed that blood enhancement was still possible after the fuming. Next, it was tested whether the powder might cause the reaction not to happen anymore; this also was not the case. Therefore, it was assumed that the blood enhancement did not take place because of the cyanoacrylate. To test this, fingerprints placed with blood were enhanced with a cyano-shot. All these fingerprints reacted with the blood enhancement technique. However, the reaction was not as good as the reaction with a fingerprint placed in blood that is not enhanced with cyanoacrylate. It is therefore assumed, that the possibility of using a blood enhancement technique after cyanoacrylate depends of the cyanoacrylate used. This is also confirmed by multiple former studies (Mutter et al., 2018; Trozzi et al., 2000). Because of this, it is recommended to research which cyanoacrylate and settings can be used best if blood enhancement techniques still must be carried out.

This research can be divided into two researches; (1) optimization of the use of BY40, and (2) replacing BY40 by enhancement with powders. By looking at the first part in a greater aspect, it can be said that there are still some profits to be made regarding the use of BY40. However, the profits found still must be validated and some further research can also be carried out. For the dilution of BY40 for example, it can be researched whether BY40 diluted even more than eighteen times, will also still give the same results. Regarding the results of lifting BY40, it is important to validate for the parameter stability, since it was already observed that some samples are less/not visible after a few days. However, this differed between the samples.

Looking at the second part of the research, it can be said that this research looks promising. However, there are still things that must be tested before this can be applied to the field. If the researches will be repeated for validation, in some cases, a greater sample size also must be used. The calculations regarding the sample sizes are shown in *Appendix V – Calculations sample size*. If the validation turns out to be working, this method mainly shows benefits and so far, no disadvantages of enhancing cyanoacrylate with powders are found. Most of those benefits also have something to do with durability; less damaging to the user (People) and environment (Planet), powders are cheaper than BY40 (Profit), and it is possible to use DNA (People). An overview of all the durable benefits of this research is shown in *Appendix VI – Durability*.

5. Conclusion

The aim of this research was to investigate whether enhancement of cyanoacrylate with powders (magnetic powder, fluorescent powder, and powder in suspension) is possible, instead of using BY40. Also, some additional insight into the use of BY40 was gained. Therefore, this conclusion will be divided into two parts; (1) optimization of the use of BY40, and (2) replacing BY40 by enhancement with powders.

Regarding the insights gained into the use of BY40, this research showed that BY40 could be better applied on the cyanoacrylate after 24 hours instead of right after the cyanoacrylate fuming, as done currently by some employees of the Dutch police (see *Appendix VIII – Interview Lauren Harder*). In addition, it also does not matter whether a 1:1 dilution of BY40 is used or a 1:18 dilution; there is no statistically significant difference between the resulting fingerprints. The benefit of using a 1:18 dilution instead of a 1:1 dilution is that less contamination of the surface takes place and it is cheaper. Also, it turned out that lifting of BY40 is possible. For this, a black lifter should be applied to the fingerprint for at least 15 minutes. The resulting lift is as good as the original fingerprint and lifting also causes no damage to the original fingerprint.

The second part of the research showed that there is no statistically significant difference between BY40 and the three different powders. Regarding the usage of powders instead of BY40, this research showed that it is best to use fluorescent powder 24 hours after cyanoacrylate fuming. For magnetic powder and suspension, there was no statistically significant difference. Tests were carried out to see on which surfaces which powders could be used best to enhance cyanoacrylate. This showed that on glass it did not matter which powder was used, on plastic, fluorescent powder worked better than powder in suspension, on aluminum, powder in suspension worked better than fluorescent powder, and on wood magnetic powder (both painted and not painted) and fluorescent powder (for not painted wood) worked better than powder in suspension. It turned out that lifting of powder in suspension works as good as lifting of BY40.

In addition, it was also tested whether the color of the fingerprints affected how well they were scored. This showed that the powders of Loci Forensics B.V. (yellow, green, and orange) gave better results than the powders of ArroSupranano (pink). Between the powders of Loci Forensics B.V. there was no statistically significant difference. This concludes that the brand influences the scoring more than the color.

The part of the research regarding the blood enhancement techniques after the use of cyanoacrylate and the enhancement of cyanoacrylate showed that blood enhancement techniques were not possible with the cyanoacrylate used. Therefore, a recommendation is to also test which cyanoacrylate can be used best if blood enhancement techniques still must be carried out.

Concluding, this research shows that enhancement of cyanoacrylate with fingerprint powders works as good as enhancement of cyanoacrylate with BY40. In addition, fingerprint powders also have advantages over BY40 regarding, health issues, environmental issues, profits regarding money, it is possible to use different powder colors instead of only yellow, it can be used on the crime scene instead of only in the laboratory, and traces containing DNA can still be used after the process of enhancement with powders. The latter is especially important since the use of DNA in forensic investigation had developed over the last years (Arnaud, 2017). Therefore, it might be concluded that validation of enhancing cyanoacrylate with fingerprint powders is probably worth the time and effort.

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Appendix I – Using the cyanoacrylate fume hood

1. Turn on the fumehood by pressing the green button.
2. Place the glass slides vertical in the fume hood (on the floor).
3. Fill the Honeywell HCM-710 humidifier with demineralized water by using the fill channel.
4. Place 3.0 grams cyanoacrylate (BVDA, B-83000) in an aluminum cup (39 mm diameter).
5. Place the aluminum cup with the cyanoacrylate on the Forensic fuming plate (hot plate).
6. Close and lock the door.
7. Insert the settings:
    a. Humidity: 80%
    b. Time: 60 minutes
    c. Temperature hot plate: 130 ^{o}C
    d. Purge time: 5 minutes
8. Press start.

Appendix II – Materials

	Manufacturer	Cat. No.	Country	Comments
Brushes	Loci Forensics B.V.	1003859	Netherlands	Continental squirrel hair brush for fluorescent powder
	Sirchie	125MD	United states	Magnetic brush for magnetic powder
Demineralized water	Albert Heijn	n.a.	Netherlands	
Ethanol	Kruidvat	n.a.	Netherlands	96%
Paint	Gamma	624005	Netherlands	Water based, grey
Camera	Nikon	D-3400	Netherlands	
Lens	Nikon	18-55mm	Netherlands	
Tripod	Manfrotto	Manfrotto 055	Italy	
Microscope	Conrad DP-M17	191377	Germany	
Lightsources	Lumatec	Superlite M 05	Germany	For latent fingerprints
	Lumatec	Superlite S 04	Germany	For other fingerprints
Cyanoacrylate fuming				
	Manufacturer	**Cat. No.**	**Country**	**Comments**
Aluminum cups	Sirchie	CNA106C	Germany	
Hot Plate		Forensic Fuming Plate		
Humidifier	Honeywell	HCM-710	USA	
Microscope slide tray				
Remaining				
	Manufacturer	**Cat. No.**	**Country**	**Comments**
Blood	n.a.	n.a.	Netherlands	EDTA added

Appendix III – Distribution samples

Table 18; samples phase 1 – optimizing time-interval (0 or 24 hours) between cyanoacrylate fuming and enhancement with fluorescent powder (Fl.), magnetic powder (Magnetic), powder in suspension (Susp.), and Basic yellow 40 (BY40).

	Donor 3	**Donor 1**	**Donor 2**	**Donor 1**
1a	Fl., 0 hours	Fl., 0 hours	Fl., 0 hours	Fl., 0 hours
1b	Fl., 24 hours	Fl., 24 hours	Fl., 24 hours	Fl., 24 hours
2a	Fl., 0 hours	Fl., 0 hours	Fl., 0 hours	Fl., 0 hours
2b	Fl., 24 hours	Fl., 24 hours	Fl., 24 hours	Fl., 24 hours
3a	Basic y, 0 hours	Fl., 0 hours	Basic y, 0 hours	Fl., 0 hours
3b	Basic y, 24 hours	Fl., 24 hours	Basic y, 24 hours	Fl., 24 hours
4a	Magnetic, 0 hours	Magnetic, 0 hours	Magnetic, 0 hours	Magnetic, 0 hours
4b	Magnetic, 24 hours	Magnetic, 24 hours	Magnetic, 24 hours	Magnetic, 24 hours
5a	Magnetic, 0 hours	Magnetic, 0 hours	Magnetic, 0 hours	Magnetic, 0 hours
5b	Magnetic, 24 hours	Magnetic, 24 hours	Magnetic, 24 hours	Magnetic, 24 hours
6a	BY40, 0 hours	Magnetic, 0 hours	Magnetic, 0 hours	BY40, 0 hours
6b	BY40, 24 hours	Magnetic, 24 hours	Magnetic, 24 hours	BY40, 24 hours
7a	Susp., 0 hours	Susp., 0 hours	Susp., 0 hours	Susp., 0 hours
7b	Susp., 24 hours	Susp., 24 hours	Susp., 24 hours	Susp., 24 hours
8a	Susp., 0 hours	Susp., 0 hours	Susp., 0 hours	Susp., 0 hours
8b	Susp., 24 hours	Susp., 24 hours	Susp., 24 hours	Susp., 24 hours
9a	Susp., 0 hours	BY40, 0 hours	Susp., 0 hours	BY40, 0 hours
9b	Susp., 24 hours	BY40, 24 hours	Susp., 24 hours	BY40, 24 hours
10a	BY40, 0 hours	BY40, 0 hours	BY40, 0 hours	BY40, 0 hours
10b	BY40, 24 hours	BY40, 24 hours	BY40, 24 hours	BY40, 24 hours

Table 19; samples phase 2 – concentration BY40 (1:1, 1:8, and 1:18).

	Donor 1	**Donor 3**	**Donor 2**
1a	1:1	1:1	1:1
1b	1:8	1:8	1:8
2a	1:1	1:1	1:1
2b	1:18	1:18	1:18
3a	1:8	1:8	1:8
3b	1:18	1:18	1:18
4a	1:1	1:1	1:1
4b	1:8	1:8	1:8
5a	1:1	1:1	1:1
5b	1:18	1:18	1:18
6a	1:8	1:8	1:8
6b	1:18	1:18	1:18
7a	1:1	1:1	1:1
7b	1:8	1:8	1:8
8a	1:1	1:1	1:1
8b	1:18	1:18	1:18
9a	1:8	1:8	1:8
9b	1:18	1:18	1:18
10a	1:1	1:1	1:8
10b	1:8	1:18	1:18

Table 20; samples phase 3 – BY40 and Lumicyano™ vs powdering with fluorescent powder, magnetic powder, and powder in suspension.

	Donor 1	**Donor 1**	**Donor 2**	**Donor 2**
1A	Basic yellow 40	Basic yellow 40	Basic yellow 40	Basic yellow 40
1B	Fluorescent powder	Fluorescent powder	Fluorescent powder	Fluorescent powder
2A	Basic yellow 40	Basic yellow 40	Basic yellow 40	Basic yellow 40
2B	Fluorescent powder	Fluorescent powder	Magnetic powder	Magnetic powder
3A	Basic yellow 40	Basic yellow 40	Basic yellow 40	Basic yellow 40
3B	Magnetic powder	Magnetic powder	Magnetic powder	Magnetic powder
4A	Basic yellow 40	Basic yellow 40	Basic yellow 40	Basic yellow 40
4B	Magnetic powder	Powder in suspension	Powder in suspension	Fluorescent powder
5A	Basic yellow 40	Basic yellow 40	Basic yellow 40	Basic yellow 40
5B	Powder in suspension	Powder in suspension	Powder in suspension	Powder in suspension
6A	Lumicyano™	Lumicyano™	Lumicyano™	Lumicyano™
6B	Fluorescent powder	Fluorescent powder	Fluorescent powder	Powder in suspension
7A	Lumicyano™	Lumicyano™	Lumicyano™	Lumicyano™
7B	Fluorescent powder	Fluorescent powder	Magnetic powder	Fluorescent powder
8A	Lumicyano™	Lumicyano™	Lumicyano™	Lumicyano™
8B	Magnetic powder	Magnetic powder	Magnetic powder	Magnetic powder
9A	Lumicyano™	Lumicyano™	Lumicyano™	Lumicyano™
9B	Magnetic powder	Powder in suspension	Powder in suspension	Magnetic powder
10A	Lumicyano™	Lumicyano™	Lumicyano™	Lumicyano™
10B	Powder in suspension	Powder in suspension	Powder in suspension	Fluorescent powder

Table 21; samples phase 4 – lifting BY40 with both black and white lifters, and with different time-intervals.

	Donor 1	**Donor 1**	**Donor 2**	**Donor 2**
1A	Black – 0 min	Black – 0 min	Black – 0 min	Black – 0 min
1B	White – 0 min	White – 0 min	White – 0 min	White – 0 min
2A	Black – 5 min	Black – 5 min	Black – 5 min	Black – 5 min
2B	White – 5 min	White – 5 min	White – 5 min	White – 5 min
3A	Black – 15 min	Black – 15 min	Black – 15 min	Black – 15 min
3B	White – 15 min	White – 15 min	White – 15 min	White – 15 min
4A	Black – 30 min	Black – 30 min	Black – 30 min	Black – 30 min
4B	White – 30 min	White – 30 min	White – 30 min	White – 30 min
5A	Black – 60 min	Black – 60 min	Black – 60 min	Black – 60 min
5B	White – 60 min	White – 60 min	White – 60 min	White – 60 min
6A	Black – 0 min	Black – 0 min	Black – 0 min	Black – 0 min
6B	White – 0 min	White – 0 min	White – 0 min	White – 0 min
7A	Black – 5 min	Black – 5 min	Black – 5 min	Black – 5 min
7B	White – 5 min	White – 5 min	White – 5 min	White – 5 min
8A	Black – 15 min	Black – 15 min	Black – 15 min	Black – 15 min
8B	White – 15 min	White – 15 min	White – 15 min	White – 15 min
9A	Black – 30 min	Black – 30 min	Black – 30 min	Black – 30 min
9B	White – 30 min	White – 30 min	White – 30 min	White – 30 min
10A	Black – 60 min	Black – 60 min	Black – 60 min	Black – 60 min
10B	White – 60 min	White – 60 min	White – 60 min	White – 60 min

Table 22; samples method 5 – different powders (fluorescent powder (fl), magnetic powder (magn), and powder in suspension (susp)) on different surface materials (plastic, aluminum, glass, and wood).

	Donor 3	**Donor 2**	**Donor 1**	**Donor 1**
1A	Plastic – fl	Plastic – magn	Plastic – fl	Plastic – fl
1B	Plastic – magn	Plastic – susp	Plastic – susp	Plastic – magn
2A	Plastic – fl	Plastic – fl	Plastic – magn	Plastic – fl
2B	Plastic - susp	Plastic – magn	Plastic – susp	Plastic – susp
3A	Aluminum – fl	Aluminum – magn	Aluminum – fl	Aluminum – fl
3B	Aluminum – magn	Aluminum – susp	Aluminum – susp	Aluminum – magn
4A	Aluminum – fl	Aluminum – fl	Aluminum – magn	Aluminum – fl
4B	Aluminum - susp	Aluminum - magn	Aluminum - susp	Aluminum - susp
5A	Glass – fl	Glass – magn	Glass – fl	Glass – fl
5B	Glass – magn	Glass – susp	Glass – susp	Glass – magn
6A	Glass – fl	Glass – fl	Glass – magn	Glass – fl
6B	Glass – susp	Glass – magn	Glass – susp	Glass – susp
7A	Wood – fl	Wood – magn	Wood – fl	Wood – fl
7B	Wood – magn	Wood – susp	Wood – susp	Wood – magn
8A	Wood – fl	Wood – fl	Wood – magn	Wood – fl
8B	Wood – susp	Wood – magn	Wood – susp	Wood – susp
9A	Plastic – magn	Aluminum – magn	Glass – magn	Wood – magn
9B	Plastic – susp	Aluminum – susp	Glass – susp	Wood – susp
10A	Plastic – fl	Aluminum – fl	Glass – fl	Wood – fl
10B	Plastic – magn	Aluminum – magn	Glass – magn	Wood – magn
11A	Plastic – fl	Plastic – magn	Plastic – fl	Plastic – fl
11B	Plastic – magn	Plastic – susp	Plastic – susp	Plastic – magn
12A	Plastic – fl	Plastic – fl	Plastic – magn	Plastic – fl
12B	Plastic - susp	Plastic – magn	Plastic – susp	Plastic – susp
13A	Aluminum – fl	Aluminum – magn	Aluminum – fl	Aluminum – fl
13B	Aluminum – magn	Aluminum – susp	Aluminum – susp	Aluminum – magn
14A	Aluminum – fl	Aluminum – fl	Aluminum – magn	Aluminum – fl
14B	Aluminum - susp	Aluminum - magn	Aluminum - susp	Aluminum - susp
15A	Glass – fl	Glass – magn	Glass – fl	Glass – fl
15B	Glass – magn	Glass – susp	Glass – susp	Glass – magn
16A	Glass – fl	Glass – fl	Glass – magn	Glass – fl
16B	Glass – susp	Glass – magn	Glass – susp	Glass – susp
17A	Wood – fl	Wood – magn	Wood – fl	Wood – fl
17B	Wood – magn	Wood – susp	Wood – susp	Wood – magn
18A	Wood – fl	Wood – fl	Wood – magn	Wood – fl
18B	Wood – susp	Wood – magn	Wood – susp	Wood – susp
19A	Plastic – magn	Aluminum – magn	Glass – magn	Wood – magn
19B	Plastic – susp	Aluminum – susp	Glass – susp	Wood – susp
20A	Plastic – fl	Aluminum – fl	Glass – fl	Wood – fl
20B	Plastic – susp	Aluminum – susp	Glass – susp	Wood – susp
21A	Painted wood - fl	Painted wood - fl	Painted wood - fl	Painted wood - fl
21B	Painted wood - magn	Painted wood - magn	Painted wood - magn	Painted wood - magn
22A	Painted wood - fl	Painted wood - fl	Painted wood - fl	Painted wood - fl
22B	Painted wood - susp	Painted wood - susp	Painted wood - susp	Painted wood - susp
23A	Painted wood - magn	Painted wood - magn	Painted wood - magn	Painted wood - magn
23B	Painted wood - susp	Painted wood - susp	Painted wood - susp	Painted wood - susp

24A	Painted wood - fl	Painted wood - fl	Painted wood - magn	Painted wood - fl
24B	Painted wood - magn	Painted wood - susp	Painted wood - susp	Painted wood - magn
25A	Painted wood - fl	Painted wood - magn	Painted wood - fl	Painted wood - fl
25B	Painted wood - susp	Painted wood - susp	Painted wood - magn	Painted wood - susp

Table 23; samples method 6 – colors (pink, yellow, green, and orange).

	Donor 2	**Donor 1**	**Donor 2**	**Donor 1**
1	Pink	Pink	Pink	Pink
2	Yellow	Yellow	Yellow	Yellow
3	Green	Green	Green	Green
4	Orange	Orange	Orange	Orange
5	Pink	Pink	Pink	Pink
6	Yellow	Yellow	Yellow	Yellow
7	Green	Green	Green	Green
8	Orange	Orange	Orange	Orange
9	Pink	Green	Pink	Green
10	Yellow	Orange	Yellow	Orange

Table 24; samples method 7 – enhancement of fingerprints (fluorescent powder (fl), magnetic powder (magn), powder in suspension (susp), and basic yellow 40 (BY40)) and enhancement of blood (ALCV or Hungarian Red (Hun Red)).

	Donor 1	**Donor 1**	**Donor 3**	**Donor 2**
1A	ALCV – fl	ALCV – fl	ALCV – fl	ALCV – fl
1B	Hun Red – fl	Hun Red – fl	Hun Red – fl	Hun Red – fl
2A	ALCV – susp	ALCV – susp	ALCV – susp	ALCV – susp
2B	Hun Red – susp	Hun Red – susp	Hun Red – susp	Hun Red – susp
3A	ALCV – magn	ALCV – magn	ALCV – magn	ALCV – magn
3B	Hun Red - magn	Hun Red - magn	Hun Red - magn	Hun Red - magn
4A	ALCV – BY40	ALCV – BY40	ALCV – BY40	ALCV – BY40
4B	Hun Red – BY40	Hun Red – BY40	Hun Red – BY40	Hun Red – BY40
5A	ALCV – fl	ALCV – fl	ALCV – fl	ALCV – fl
5B	Hun Red – fl	Hun Red – fl	Hun Red – fl	Hun Red – fl
6A	ALCV – susp	ALCV – susp	ALCV – susp	ALCV – susp
6B	Hun Red – susp	Hun Red – susp	Hun Red – susp	Hun Red – susp
7A	ALCV – magn	ALCV – magn	ALCV – magn	ALCV – magn
7B	Hun Red - magn	Hun Red - magn	Hun Red - magn	Hun Red - magn
8A	ALCV – BY40	ALCV – BY40	ALCV – BY40	ALCV – BY40
8B	Hun Red – BY40	Hun Red – BY40	Hun Red – BY40	Hun Red – BY40

Appendix IV – Settings camera

All samples are photographed with a Nikon D-3400 and 18-55 mm lens. The settings used are shown in the table below.

Table 25; settings camera.

	A	Shutter speed	ISO	Focal length	Light	Filter
BY40	f/5.6	1/200	100	34 mm	440 nm	Yellow
Cyanoacrylate	f/5.6	1/25	400	55 mm	None	None
Fluorescent powder (green)	f/5.6	1/1000	100	34 mm	440 nm	Yellow
Fluorescent powder (orange)	f/5.6	1/1000	100	34 mm	460 nm	Light orange
Fluorescent powder (pink)	f/5.6	1/1000	100	34 mm	460 nm	Light orange
Fluorescent powder (yellow)	f/5.6	1/1000	100	34 mm	440 nm	Yellow
Latent	f/5.6	1/25	400	55 mm	White	None
Lifts	f/5.6	1/13-1/400	100	34 mm	440 nm	Yellow
Lumicyano™	f/5.6	1/25	400	55 mm	320-400 nm	Orange
Magnetic powder	f/5.6	1/1000	100	34 mm	440 nm	Yellow
Powder in suspension	f/5.6	1/1000	100	34 mm	440 nm	Yellow

Appendix V – Calculations sample size

At this appendix, the sample size is calculated per group which had to be used to get a desired standard deviation (SD). This is a SD of 10% and so based on a scale from 0 to 4, a SD of 0.4. For this, the following equation is used:

Equation 1; calculation sample size with post-hoc power analysis.

$$calculated\ sample\ size = (\frac{current\ SD}{desired\ SD})^2 * current\ sample\ size$$

Table 26; calculated sample sized phase 1.

	Current SD	Current sample size	Calculated sample size
Fluorescent 0 hours	0.54	10	19
Fluorescent 24 hours	0.56	10	20
Suspension 0 hours	0.88	10	47
Suspension 24 hours	0.48	10	15
Magnetic 0 hours	0.80	10	40
Magnetic 24 hours	0.65	10	27
BY40 0 hours	0.57	10	21
BY40 24 hours	0.75	10	35

Table 27; calculated sample size phase 2.

	Current SD	Current sample size	Calculated sample size
Dilution 1:1	0.54	10	19
Dilution 1:8	0.63	10	25
Dilution 1:1	0.63	10	25
Dilution 1:18	0.52	10	18
Dilution 1:8	0.79	10	40
Dilution 1:18	0.71	10	32

Table 28; calculated sample size phase 3.

	Current SD	Current sample size	Calculated sample size
BY40	0.42	7	8
Fluorescent	0.63	7	18
BY40	0.63	7	18
Magnetic	0.46	7	10
BY40	0.78	6	23
Suspension	0.70	6	19
Lumicyano™	0.66	7	20
Fluorescent	0.37	7	6
Lumicyano™	0.48	7	11
Magnetic	0.82	7	30
Lumicyano™	0.40	6	7
Suspension	0.84	6	27

Table 29; calculated sample size phase 4 – original fingerprint.

	Current SD	Current sample size	Calculated sample size
Black lifter, 0 min	0.74	8	28
Black lifter, 5 min	0.73	8	27
Black lifter, 15 min	0.54	8	15
Black lifter ,30 min	0.90	8	41
Black lifter, 60 min	0.92	8	43
White lifter, 0 min	0.84	8	36
White lifter, 5 min	0.71	8	26
White lifter, 15 min	0.84	8	36
White lifter ,30 min	0.70	8	25
White lifter, 60 min	0.64	8	21

Table 30; calculated sample size phase 4 – lift.

	Current SD	Current sample size	Calculated sample size
Black lifter, 0 min	0.47	8	12
Black lifter, 5 min	0.57	8	17
Black lifter, 15 min	0.60	8	18
Black lifter ,30 min	0.68	8	24
Black lifter, 60 min	1.02	8	53
White lifter, 0 min	0.72	8	26
White lifter, 5 min	0.53	8	15
White lifter, 15 min	0.45	8	11
White lifter ,30 min	0.54	8	15
White lifter, 60 min	0.56	8	16

Table 31; calculated sample size phase 4 – original fingerprint after lifting.

	Current SD	Current sample size	Calculated sample size
Black lifter, 0 min	0.62	8	20
Black lifter, 5 min	0.76	8	29
Black lifter, 15 min	0.55	8	16
Black lifter ,30 min	0.90	8	41
Black lifter, 60 min	0.90	8	41
White lifter, 0 min	0.68	8	24
White lifter, 5 min	0.82	8	34
White lifter, 15 min	0.67	8	23
White lifter ,30 min	0.50	8	13
White lifter, 60 min	0.72	8	26

Table 32; calculated sample size phase 5 – glass.

	Current SD	Current sample size	Calculated sample size
Fluorescent	0.89	7	35
Magnetic	0.69	7	21
Fluorescent	0.35	7	6
Suspension	0.51	7	12
Magnetic	0.51	6	10
Suspension	0.78	6	23

Table 33; calculated sample size phase 5 – plastic.

	Current SD	Current sample size	Calculated sample size
Fluorescent	0.71	7	23
Magnetic	0.66	7	20
Fluorescent	0.52	7	12
Suspension	0.81	7	29
Magnetic	0.59	6	14
Suspension	0.79	6	24

Table 34; calculated sample size phase 5 – aluminum.

	Current SD	Current sample size	Calculated sample size
Fluorescent	0.51	7	12
Magnetic	0.49	7	11
Fluorescent	0.53	7	13
Suspension	0.78	7	27
Magnetic	0.31	6	4
Suspension	0.93	6	33

Table 35; calculated sample size phase 5 – wood (not painted)

	Current SD	Current sample size	Calculated sample size
Fluorescent	0.32	7	5
Magnetic	0.27	7	4
Fluorescent	0.36	7	6
Suspension	0.43	7	9
Magnetic	0.31	6	4
Suspension	0.21	6	2

Table 36; calculated sample size phase 5 – wood (painted)

	Current SD	Current sample size	Calculated sample size
Fluorescent	0.76	7	26
Magnetic	0.75	7	25
Fluorescent	0.28	7	4
Suspension	0.073	7	1
Magnetic	1.28	6	62
Suspension	0.41	6	7

Table 37; calculated sample size phase 6.

	Current SD	Current sample size	Calculated sample size
Pink	0.22	10	3
Yellow	0.53	10	18
Green	0.36	10	8
Orange	0.43	10	12

Appendix VI – Durability

Current research

During this research, the three P's (People, Planet, Profit) were considered. An overview is given in Table 38.

First, gloves were used to protect the user. Even though this might seem bad for the Planet and Profit, gloves are necessary during this research. First, to protect the user from dyes (People). But second, to prevent placing unwanted fingerprints on the glass slides, and having to redo the experiment (Planet and Profit). Indirectly, the gloves prevent the experiments from failing and therefore having to redo the experiments and thus having to use more materials (cyanoacrylate, dyes, powders) as necessary.

Secondly, a fume hoods are used. With this, both a regular fume hood and the cyanoacrylate fume hood are meant. The fume hood is used to protect the user from inhaling vapors of the fingerprint powders (People). In addition, the cyanoacrylate fume hood contains carbon filters which causes the vapors of the cyanoacrylate not to go into the environment (Planet).

Third, reusing glass slides. If an experiment failed, the glass slides were cleaned in an ultrasonic bath and afterwards reused again. This way, no glass slides are wasted (Planet and Profit).

Fourth, BY40 was diluted during this research. Since one of the phases showed that diluting BY40 does not affect the resulting fingerprint, the diluted BY40 was used for the remainder of the experiments which brings down the costs since BY40 is more expensive than ethanol (the BY40 was diluted in ethanol) (Profit).

Last, calibration of the fume hood took place. Therefore, it was determined how much cyanoacrylate had to be used. This way, as little as possible cyanoacrylate was wasted (Planet and Profit).

Table 38; overview durability.

	People	Planet	Profit
Gloves	X	(X)	(X)
Fume hood/filters	X	X	
Reuse glass slides		X	X
Dilute BY40			X
Calibration fume hood (CA)		X	X

Future aspects

People/planet

As already mentioned in the introduction, BY40 is currently used at the Dutch police and the Netherlands Forensic Institute (NFI) for enhancing cyanoacrylate. One of the disadvantages is that BY40 is dissolved in ethanol, which is damaging to both the user (People) as the environment (Planet). If BY40 can be replaced with an alternative that causes less damage to both the used as the environment, this would be durable. Three different options (magnetic powder, fluorescent powder, and powder in suspension) were tested. These powders are less damaging to both the environment and the user. This research showed that these alternative methods work just as good as BY40. If the Dutch police and the NFI decide to use these powders instead of BY40, this would be durable. In addition, BY40 is also a liquid and the procedure of BY40 contains not only BY40, but the fingerprint also must be washed with water after applying BY40. Concluding, a liquid is used twice. The NFI itself already states that DNA-investigation is not performed after BY40 since the chances are high that DNA

is washed away during the procedure. Therefore, powder (magnetic and fluorescent) has another advantage over BY40; the chances of gaining a DNA-profile is higher. Gaining more evidence (only a fingerprint vs a fingerprint and a DNA-profile) increases the chances of finding a perpetrator (People).

In addition, this research also showed that lifting of BY40 is possible. Till now, this was not carried out at the Dutch police (see *Appendix VIII – Interview Lauren Harder*). Lifting BY40 is usable in cases where for example the surface the fingerprint was placed on also fluoresces or if the fingerprint was placed on a curved surface and you want to have it flat. This way, the enhanced fingerprint can be used if beforehand this might not have been possible (e.g. because the surface fluoresces). This, again, has advantages for the process of finding a perpetrator (People).

Profit

This research has shown that BY40 can be used in a dilution instead of undiluted. Dilution can take place up to eighteen times.

In addition, this research showed that enhancing cyanoacrylate with powders shows potential. Since powders are cheaper than BY40, this can save money.

Powders are also cheaper than BY40.

Appendix VII – MSDS BY40

BY40 powder

Safety ratings:

- Health: 2, moderate
- Flammability: 1, slight
- Reactivity: 0, none

http://sds.chemtel.net/webclients/safariland/finished_goods/Pioneer%20Forensics%20-%20PF013%20-%20PF014%20-%20Basic%20Yellow%2040%20Powder%20-%20300%20Percent%20and%20680%20Percent%20Mixture.pdf

Ethanol

Safety ratings:

- Health: 2, moderate
- Flammability: 3, severe
- Reactivity: 1, slight

https://www.scribd.com/document/96820890/Msds-Ethanol

Methanol

Safety ratings:

- Health: 2, moderate
- Flammability: 3, severe
- Reactivity: 0, none

https://www.labchem.com/tools/msds/msds/VT430.pdf

Appendix VIII – Interview Lauren Harder

For this research, Lauren Harder was asked some small questions regarding the current use of BY40 at the Dutch police. Lauren Harder is a laboratory coordinator fingerprint/DNA of the Dutch police. An email was sent to her on the 27th of May 2020, at 11:05h. She replied on the 27th of May 2020, at 12:03h.

How often is a fingerprint on a non-porous surface enhanced with cyanoacrylate (%)?

Almost always, 98%? Exceptions include traces in blood and wet objects.

On what surfaces is cyanoacrylate often used?

Plastic, glass, coated materials, firearms (often a combination of metal and plastic).

How often are fingerprints that are enhanced with cyanoacrylate, enhanced with BY40 (%)?

It is getting less. After cyanoacrylate, we often use light sources. It will be around 5%.

Is BY40 applied right after cyanoacrylate fuming or is there some waiting time in between?

Some employees wait, others apply BY40 right away.

Is BY40 used as provided by for example the BVDA, or is it diluted before use?

As provided by the BVDA.

Does BY40 gets lifted sometimes?

No.